STATIONARY ENGINE DRIVING

MICHAEL REYNOLDS.

I remain Your obed^{t} Serv^{t}

James Watt

London: [illegible] & C^{o}. Stationers Hall Court

STATIONARY ENGINE

A PRACTICAL MANUA

FOR ENGINEERS IN CHARGE OF STATION

BY MICHAEL REYNOL

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AUTHOR OF "LOCOMOTIVE ENGINE DRIVING," "THE MODEL LOCOMOTI
AND ENGINE-BOY," ETC.

With Numerous Illustrations

Capio Lumen

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TO

THE ENGINEMEN AND FIREMEN

OF

STATIONARY ENGINES

THROUGHOUT THE UNITED KINGDOM

THIS WORK

IS

Dedicated

AS A TRIBUTE OF RESPECT AND REGARD

BY THEIR SERVANT

THE AUTHOR

PREFACE.

I HOLD a very strong opinion that, no matter how good and well tested a steam-boiler or a steam-engine may be, accidents to boilers and machinery will take place, so long as the men in charge are not put to any qualifying test themselves. Owners of steam-boilers properly insist upon their being made of the best material, on the latest pattern, and they do not object to paying a good price for a good boiler; but in many instances the matter begins and ends here. It is not an uncommon occurrence to find men in charge of fine machinery who cannot explain a tenth part of the movements before them. Of this we cannot complain, because when a man is out of employment he is ready and willing to take charge of an engine, even if he knows nothing about it, provided he can persuade the owner of such machinery to take his word for his competency.

I have been conversant with steam-engines for a quarter of a century, and not without observing the modes by which men have been enabled, in many instances, to raise themselves to the rank of enginemen, and to have charge of engines, boilers, and machinery.

The skilled mechanical engineman's eye is trained; it is full of activity and adjusted in its range by experience, and it detects the very appearance of evil. Therefore the man

full of expedients, full of opinions, full of facts, and wants be nipping the evil in the bud. Part of this effect is due the sheer quantity of mental work thrown in with the ual toil; but in many instances these acquirements are idered superfluous naughtiness, and a way of making : for making money by overtime. The unskilled engine- is in many cases the simple, honest man, who will the machinery without any repairs month after month a shaft breaks, in consequence of a bearing being in of adjustment, or of a rivet leaking week after week rded, until corrosion sets in; or he will overload the alves, by laying on scrap iron, or by moving the and so make one boiler do the work, at the risk of limb.

s I have already said, no one can blame a man for is way into the engine-house. The law does not with the matter, and the loss arising from bad nts is borne by the master. I have reason to t every man who engages himself as an engine- iced to do so from a good motive.

t in writing this work is to give such information y power as seems to me calculated to raise the gineer in this country—the land of steam· to then and induce them to pursue their inquiries written by better pens than mine.

and put together such information as I of benefit to those who wish to learn best Stationary Engine practice. There men who have not had an opportunity of sing engine, such as is supplied for large and who have had no experience either

with them or with Galloway boilers, though they cannot tell how soon they may be called upon to manipulate such works; and therefore I have supplied for their information drawings of engines and boilers, with keys thereto. The elements of the stationary engines are described, and the principles of construction of the Galloway, Cornish, and Lancashire boilers are set forth, whilst the causes of failures are analysed and exposed. The various causes tending to produce explosions of boilers are discussed at length, and the errors often committed in shutting down valves are referred to; whilst the management of the fire and the principle of combustion are fully explained.

I have also added a chapter on the use of the indicator, with examples in the arithmetical portion, of the method of calculating horse-power from diagram cards.

In the endeavour to accomplish my work in a manner both instructive and agreeable, I have now and again departed from the general course to notice some particular point: especially in those portions of the work connected with the name of Watt, whose portrait forms the frontispiece to this work.

Some time ago an effort was made to establish a system of certificates of proficiency for enginemen, by means of which I did hope to see the vocation of engine-driving brought up to a high standard, but, from the very limited number of men who felt disposed to assist at the work, it was evident that the men themselves did not care for certificates, whilst the masters did not want them. I have therefore now concluded that the only means is to place within the reach of the men such books as shall elevate their ideas, and induce a manly independence of thought and opinion.

Finally. It may possibly be asked what are my qualifications for writing upon the subject of this work. I may, in answer, briefly state that I served my apprenticeship in a general engineering shop, working at the lathe and vice, and that, afterwards, I have been engaged in various parts of England, on Locomotive, Tractive, Stationary, and Portable engine work.

MICHAEL REYNOLDS.

STANDEFORD, *August*, 1880.

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STATIONARY ENGINE DRIV

CHAPTER I.

INTRODUCTORY NOTICE OF THE STEAM-ENG BOILER.

ENGLAND is the birthplace of the steam-en invention has been a grand triumph over tl which nature has placed at our disposal. T limit to the sphere of its usefulness, nor c measure the benefits which directly and accrue to society from its extended employn

All these benefits are simply due to the the natural principle, that water can be co a gas. The principle itself appears very the discoveries that led to the practical a the principle as a source of wealth, were p after a long series of trials and failures, perience thus laboriously accumulated.

It is on record that for two thousand ye only used as a source of amusement; it w bauble to be sure, and that was all. But very often spring from small beginnin discovery of the pendulum was the result

B

amp in the centre of a church. By a pended across the path of Sir Samuel prompted to the conception of a sus- Galvani observed that a frog's leg it was placed in contact with different s laid the foundation of a train of in- ed up to the electric telegraph. Colum- reeds and stranger rushes floating in quay of Oporto, and he was instigated isitors to undertake a voyage by which was discovered. With regard to the steam as a motive-power, its history templation a marvellous train of con- lly deduced or tentatively arrived at, emselves, and furnishing a narrative f lapse and loss of choice spirits, the ose enthusiasm lingers to this day. " writes an eminent authority, "some e anxious hope and fear of each suc- before his conceptions were clothed in al form—the parental grief or joy as d in infancy or arrived at manhood

lose of the seventeenth century there s and sudden development of the mind ites Lord Hatherly, to the Reforma-

lustrious men of the time were mighty leeds. Newton—of whom it was written 'Let Newton be!' and all was light," and Bacon; these, together with a few e world of ideas upside down. The s founded, where the chaff was win-

nowed from the wheat. It was light
for great designers, a resort " who
recommendation either knowledge, pro
From this time the force of steam
ployed : first, it is true, only to burst
last to drive a cotton-mill with 10,000
At first steam was regarded as a
horse, having a magnificent spirit, wi
and muscles, the puff of whose nostrils
Some were decided by their fears,
afraid of it ; whilst others determined
aggression and investigation. The pi
anders " were Papin, a French physic
English miner ; Newcomen, an Engl
Potter, an English peasant-boy ; Fitz
professor ; Watt, a Scottish mechan
English mechanic ; Cartwright, an En
clergyman ; Murdoch, a Scottish me
blower, an English mechanic ; Trevit
engineer ; Stephenson, an engineman.

Among the innumerable inventions
ministering to the necessities and luxu
has played so important a part as th
By its power the great deep is crossed
in storm, independently of tides. I
treasures from the bowels of the earth
for the service of man. It drains the
the lodes containing the ore are m
Communities are brought closer tog
advantages which were confined to a fe
tended to many. Illimitable is the ad
steam-engine ; and every day improve
made in its structure and application.

the subject, it will be our duty to notice for the information of young enginemen such types of engines and boilers and their appendages as prevail at the present day.

Classification of Steam-Engines.—Stationary engines re distinguished as either vertical, horizontal, or beam ngines.

When the cylinder is suspended above the crank-haft it is a vertical engine. When the cylinder is xed in the same horizontal line as the crank-shaft it a horizontal engine, or, as the enginemen *call* it, a lie-down."

When the cylinder is up on end, and the piston-rod attached to a beam which is suspended at its centre, is a beam engine. When the cylinder is on end, d the piston-rod is attached to one end of the beam, ile the other end of the beam is suspended on a lar, it is a grasshopper engine. When the cylinder suspended at the centre by trunnions, with the nk-shaft either above or below the cylinder, it is an llating engine.

'or each of these types, terms are employed to denote specialities.

hen the cylinder is suspended vertically in a cast-frame, the slide-bars forming a portion of the it is an inverted-cylinder engine, or, what is the thing, an inverted direct-acting engine. Some-wo cylinders are placed alongside of each other positi on, between the frames, with the steam-etween them, and the crank-shaft being below. e is also a type of engine called the "trunk " specially constructed to reduce the distance the centres of the crank-shaft and the cylinder

in direct-acting engines, retaining at the same time sufficient length of connecting-rod.

Its principle is as follows:—A hollow cylindrical casing or "trunk," from which it takes its name, is fitted fast upon the piston. The trunk works through both ends of the cylinder, and is fitted with a stuffing-box at each end. One end of the connecting-rod is attached to the face of the piston within the trunk; the other end of the connecting-rod being attached to the crank-pin. The internal diameter of the hollow trunk is sufficiently large to permit the vibration of the connecting-rod within it. Thus, as already mentioned, whilst a long connecting-rod is obtained, the distance between the centres of the crank-shaft and the cylinder is reduced. Such engines are often used in steamships.

Again, some engines, which may be constructed according to any of the foregoing types, are constructed as compound engines. They consist of two cylinders, in which the steam, after having been used in one cylinder, is used again in the second cylinder, instead of being exhausted at once into the atmosphere or the condenser.

The engine which now claims our special attention, and which has been selected for illustrating the description of the steam-engine in detail, and for instructing enginemen in the management of engines, is the beam engine, inseparably associated with the name of Watt. There is no other engine that commands our admiration as engines of this old-fashioned design, when carefully designed and artistically surrounded. Since the year and the day it left the hands of Watt it has afforded scope for the exercise of ingenuity, talent,

ɜrseverance. There has not been much to alter. aterial is the same, so is the moving power, and is the principle; but one thing has improved hands of his successors, which the great man y never dreamt of, and that is the rapid and ·ly exhaustless demand for engines.

lowing out of a cork from a flask of water, the ɹure of which had been raised by the heat of ndicated to man a field of labour and research, many labourers have been working. At practical results were of a very limited ; the workers were too wide apart. The isolated individuals were frequently con- heoretical reasonings and calculations, not y biassed by prejudice, party spirit, or untenable hypotheses.

at first, therefore, was slow, and the mode lesson was applied exhibits a characteristic e human mind, which is apt to prefer the ad of abstract reasoning to the direct eriment. Each scholar reasoned for him- nany diversified opinions, replete with so erroneous, unscientific, and contradictory. not be made; the truth exists.

erties of steam became revealed to the nts were created. Brindley confined en vessels, but there were threatening ndant on the use of such an unstable l. Stone vessels were employed in an of forms; and these in their turn were a long period of time, steam was used r in a negative sense, as was shown in engine, in which steam of a low pres-

sure was employed to produce a vacuum under the piston.

The difficulty of constructing vessels of sufficient strength was one of the chief impediments in the way of using high-pressure steam; and although the spherical cast-iron boiler was an advance upon all others, it was found to be untrustworthy, and was replaced by wrought-iron boilers. The variety of shapes in which boilers have been made is the outcome of a desire to obtain a safe boiler, an effective boiler, a convenient boiler, and a durable boiler. The boiler which combines these four qualities, and possesses each quality in an eminent degree, may be considered a perfect boiler. The material used in making boilers is the outcome of the need for obtaining great tensile strength and ductility. These are the first considerations. In an economical point of view, for generating steam, irrespective of cost, copper is the most eligible metal for conducting heat, as its conducting power is more than double that of iron; but this advantage is counter-balanced by the fact that copper suffers such a loss of cohesive strength by elevation of temperature, even to a moderate extent, as to cause it to be superseded by wrought-iron, except for special purposes unconnected with strength. Besides its heat-conducting power, which recommends it to the notice of locomotive builders, it is also recommended by the mode in which it is fractured when an explosion takes place; it tears open, whereas iron is blown to pieces.

Wrought-iron boilers at first were either globular or hemispherical, with flat or with concave bottoms. They were as nearly spherical as possible, and so presented the best form to resist the internal pressure of

the steam. They were deficient in heating surface, and were great wasters of fuel. Under these circumstances Watt was induced to design the "waggon" boiler, which was so called from its likeness to mill waggons, which were covered in to keep the contents dry.

This boiler, having by its form a greater area of heating surface, was capable of evaporating more water per hour than any of its predecessors; and, besides, the gaseous products of combustion, having a long run of heating surface, remained longer in contact with the plate surface, so that before they reached the chimney they were cooled down by the absorption of their heat to a temperature very much lower than that of the gases which escaped from the earlier kinds of boilers. Watt held that there was a considerable waste of fuel in producing steam by intensity of heat directed upon a small surface; and he preferred to apply heat at a moderate temperature, providing a large area of surface on which it should act.

The cost of fuel for producing steam for the large Cornish engines being an item of importance, the Cornish engineers gave the matter of steam generation every consideration. The "Trevithick boiler" was brought out. It was advertised to be superior in economy, and capable of bearing a pressure of 30 lbs. per square inch. This boiler is now known as the Cornish boiler; cylindrical, with flat ends, having an internal flue and fire-grate. The flame, proceeding from the fire at one end of the flue, traverses the whole length of the flue, and the gases are returned along the bottom of the boiler to the front, thence along the sides to the chimney, by which the actuating force of draught is generated. Sometimes the flame takes

the side courses first, after leaving the flue, and then passes under the boiler to the chimney. Whichever way it is done, the object is to expose as much boiler surface as possible to the hot gases, so that they shall not leave the boiler until they are reduced as nearly as possible to the temperature of the water in the coolest part of the boiler. By this means the consumption of fuel can be reduced and the evaporative power of the boiler improved. In consequence of the weakness of a single internal flue, when of large diameter to receive a large grate-area, two flues instead of one flue were adopted in Lancashire, and hence the name, "Lancashire boiler," given to a boiler with two flues, to distinguish it from the "Cornish boiler," which has one flue only.

Still more to economise the heat and increase the amount of heating surface, the "Galloway boiler" was designed. It is a great favourite with steam-users, and it satisfies all the requirements of the day. To design a boiler for high-pressure steam, that should be at once as safe as, and yet more economical than, its predecessors of the same class, demanded no small amount of physical and mechanical knowledge.

CHAPTER II.

PROPERTIES OF THE MATERIALS OF WHICH ENGINES AND BOILERS ARE MADE.

WE owe to our native skill in working metallic ores the fabrication of iron, steel, copper, and brass, the materials of which engines and boilers are manufactured.

Cast-iron is used for such parts as require a great degree of rigidity or stiffness—as the foundation-plate, the cylinder, cylinder-cover, steam-chest, condenser, piston, junk-ring, columns, plummer-blocks, wall-boxes, and the fly-wheel.

The fittings of the boiler consume a small portion of cast-iron—as the furnace-front, the dead-plate, the fire-bars, stop-valves, and steam-pipes.

Wrought-iron is used chiefly for those parts which are subjected to great strains or to sudden shocks, and also for the parts of the engine which are in motion—as the piston-rod, connecting-rod, crank, crank-shaft, excentric-rods, excentric-hoops, cross-head, and parallel-motion. The boiler is constructed entirely of wrought-iron.

Steel is coming largely into use, and it is, in many cases, taking the place of wrought-iron without interfering with the use of cast-iron. Many absurd objec-

tions against steel have been withdrawn been proved by important experiments treacherous as some persons have tried The use of steel for boiler-making is greatl crease. The increase is due to the m produced of such a mild quality as to warr duction into the boiler-yard, and to adapted for the construction of steam-boi largely used for bushes, to reduce the we likewise for crank-pins, parallel-motion Its introduction into any portion of supersede wrought-iron requires delibera iron can resist a great degree of tors steel cannot be twisted, it snaps short of

Copper is mostly used alloyed with hard metal—gun-metal. It is used f bearings for supporting the crank-shaft other revolving pieces. The big-end ar of the connecting-rod are lined with it.

Brass is also an alloy of copper w comparatively soft, and is used for mo

White-metal is used and applied as metal bearings on account of its an perty. Sometimes it is used for th but the journal bedded entirely in w be allowed to revolve without oil f because the metal is liable to melt at temperature. On the contrary, if properly lubricated with oil, for smal at a high speed, it is more serviceab for bearings.

Muntz-metal is used for bolts and action of steam and grease. It is

inside steam-chests and under water, as it is not liable to be corroded, or otherwise affected by salt-water.

The whole of the metals of which the engine and the boiler are composed, are full of interest. They are distinguished differently—some for their lustre, ductility, malleability, and tenacity; others are elastic. Some metals combine together in their melted state, whilst there are others whose characters and natures are changed completely when combined with other metals. Metals are all fusible, but they melt at different temperatures. An alloy or mixture of metals sometimes destroys the malleability and ductility possessed by either metal singly.

There is no doubt that iron was worked for the purpose of commerce in this country by the Romans, and that the process was vastly improved by the Danes when they established themselves in this country. Foot-blasts were employed, worked by a boy stepping alternately from one bellows to the other, and forcing a current of blast, through two cow-hides, into a smelting-furnace, into which it was carried through a bamboo stick. The lad kept on working the bellows until the metal was fused.

The most tractable ores were selected, and they were smelted with charcoal as the fuel. These circumstances sufficiently account for the excellent quality of the iron produced.

In the reign of Elizabeth, a remarkable epoch, in which the powers of the understanding were marvellously developed, patents were granted for making iron by means of pit-coal instead of charcoal; but prejudice, as usual in this country, set its face against any change, and people determined that they would not

buy iron made with coal. By such scheme was defeated, and the price of iro under the control of the iron-masters, mously in price, and the home manufa declined, so much so that the bulk of sumed in this country was imported from Russia. At the same time it was well kn means of pit-coal for heating instead o could have been obtained at home at a le the imported iron. One great drawback facture of iron was removed by the introd steam-engine as the motive-power. furnace-bellows were worked by bullo blast was of an inferior force; but wh engine was set to work to force the blas and more complete combustion was eff rience taught the manufacturer of iro engine-blast, coke could be efficiently used ore. Steps of improvement were made gr an increase of capacity of blowing-cylind crease of furnace. New vigour was im rapid progress was made in the iron tr country. It is interesting and useful to kn impetus thus communicated to the iron m was due to the machine, the management of the subject of this work.

A brief sketch will now be given of the which iron is extracted from its ores, and br the state of pig-iron.

Unlike the ores of many other metals, iron is not distributed in layers, or scattered particles, but the ore is thickly stratified, and many acres.

Calcined Ore.—In all iron ores, the iron is in the state of an oxide; that is to say, it is chemically compounded with oxygen. In most kinds of ore the oxide of iron is combined with a considerable proportion of earthy or stony matter, besides which, oxygen, sulphur, arsenic, and manganese are present. To extract these without melting the ore, recourse is had to a process known as calcination. It consists in exposing the substance to a strong heat so as to dissipate the volatile portions.

Smelting.—The ore having been deprived by calcination of sulphurous, arsenical, and other volatile matters, it is introduced into the smelting-furnace, or, what is the same thing, the blast-furnace, from the top of which huge flames may be seen to issue by night.

The blast-furnace is forty or fifty feet high, and the ironstone (ore) is carried to the top, either up an inclined plane in waggons, or by a steam-crane directly. Besides the ironstone and the fuel, a flux is necessary to assist at the separation of the iron, effecting, in conjunction with the intense heat, what could not be performed by the process of calcination. Limestone is a flux. When introduced into the heated furnace, containing coke, with the ironstone, the ore is softened at the surface, and unites with the earthy matter of the flux, forming a lava which is incapable of holding the globules of hot metal, now, by the aid of the combined agents coke and blast, reduced to a liquid form. When the required quantity of melted iron has been collected at the bottom of the furnace, it is tapped; when the metal rushes out and distributes itself, first by a principal channel, which is called the *sow*, and then into

branch channels called the
that these terms were sugges
a tolerable acquaintance with

The formation of these ir
As the stream of metal iss
infinite number of brilliant
ferent directions, attended w
colour.

Refining Pig-iron.——The p
and subjected to a fierce bl
the carbon is driven off. A
refiner taps the furnace, and
and cooled by water. This
but it is considered necessar
mentioned, and for preparing
furnace.

Puddling.—The iron from
broken into short lengths an
furnace, and placed on the
the heat of a strong flami
made to impinge downwards,
interior of the furnace.

The puddle balls, under th
heat, heave and boil, and app
bustion; but this is a sign th
it shows to him that the me
because it is now losing i
becoming a mass. The puddl
of iron about in the furnace,
becomes sufficiently tenaciou
about half a hundredweight.
batch of such balls, which lo
oven. In fact, the puddle

iron. As soon as he finds the iron loaves are well baked, ınd that is known by the iron changing from a liquid nass to a solid lump, it is ready for the shingler.

Rolling.—The shingler receives the ball of metal rom the puddler, whose furnace is hard by. As quick s thought the hissing mass in the furnace is eagerly ıatched up, on the puddle-furnace door being opened, ıd with a pair of tongs it is put through the rolls, hich revolve with great velocity, driven by a steam-gine, of which the fly-wheel alone may weigh twenty ıs, going at the rate of sixty miles an hour.

The iron is passed between the rolls to and fro ernately, until it is drawn down to the intended ntling and length. It is now in the condition of ›ught-iron.

'iling.—The rough bars, after they have gone ›ugh the rolls for the first time, and before they cold, are cut into lengths of about a foot each. A ıber of them are piled one upon another to form a *n*; and, with an instrument called a *peel*, each pile aced on the bed of the *balling*-furnace. When the r considers the blooms sufficiently heated—and to le this point an eagle eye and a sound judgment required—they pass through a variety of rolls, ly, *flat*, *square*, and *round*, and finally through the ing rolls, after which they are taken away to cool lat surface. This iron is common bar-iron.

t Iron.—The term "best" has a wide significa-ut it simply refers to iron that, after having rought to the state of common iron, again hrough the process at the balling-furnace and t and piled, &c. This treatment has the effect, ᵌ, of driving out of the metal the foreign

matter that has remained in
fying process, and it confers
degree of fibrousness, toughnes
iron is best iron, consisting
is made up into a pile, and pla
intense heat. The pile, after
welding temperature, is put
the pieces well united. It i
nace, and when the *bloom* is
passed through the rolls, or ma
by means of the steam-hammer
"best-best iron" is intended to
superlative degree. This quality
the bars, and piling and shing
again. Great care is required n

Charcoal-iron.—Charcoal-iron
been smelted in the ordinary way
with wood-charcoal. It is prepar
and rolled for the market like
coal-iron has a very smooth skin;
tinning, or for purposes where the
to be particularly clean and free fr

A bird's-eye view of the process
now been presented, but, before co
subject, something is required to be
purchased by marine-store tradesmen

There is "coach-tyre," "nut," and
The terms explain themselves:—"c
large pieces; "nut" in small scraps;
sists of pots and kettles. The smal
common iron—nut and bushel. Th
very superior; it is laid into bundles
heated and shingled into blooms, w

heated and passed under the rolls. It is evident that this iron, being originally of the best quality, is much improved by the time it returns to the rolls. It has a history of its own: it may have passed through a blacksmith's shop in every county—at one time a plough-share, at another a horse-shoe; a hinge for a church-door, and back again into a plough; finally, it may have formed a portion of a coach-tyre for the chaise of the lord of the manor. At each stage it is *improved in the fire*, and by hammering; so that, when it presents itself for re-manufacture, it repeats the refining process of the first maker. Thus one can understand why scrap-iron is better than, and superior to, iron newly made from pig. Extreme tenacity is acquired in proportion to the amount of treatment, in the shape of refining and by hammering, which the iron has experienced.

Steel.—This metal holds a position between cast-iron and wrought-iron; that is to say, with respect to the proportion of carbon it contains. Wrought-iron may be called pure iron, steel less pure, cast-iron least pure. Steel is a very dense material, rendered dense by intimate combination with a minute portion of carbon. Steel can be manufactured in several ways; but it will suffice to state one way by which we may be led to notice recent improvements. What is necessary is to explain what steel is, which can be done in a brief notice.

To make steel from iron, after iron is purified of all foreign matter, it is allowed in a furnace to take up a portion of carbon, and it is this minute portion of carbon, from 2 per cent. to $\frac{1}{3}$ per cent., free from other elements, that gives the iron the steely nature which

renders it dense and hard. The between cast-iron and steel is, that the dense than the latter, and is combinec proportion of carbon and other matter. the difference of treatment may be in making steel, the same result is soug manufacturers prefer to subtract the pr of the carbon from the pig whilst it is i molten lava, by blowing a strong curr into it, which drives out the carbon number of brilliant sparks. Others pre high class of steel by the process of re and hammering—that is by expulsion obtained pure iron, they then give it a carbon, by which it is made into steel.

Cast-steel.—The finest steel, and the most purposes, is that which has under cess of fusion, and subsequently a good

CHEMICAL COMPOSITION OF IRON AND

	Iron.	Carbon.	Silicon.
Cast-iron	91	5	2
Wrought-iron . .	99·5	0·035	0·076
Steel	98·6	1·4	—

The properties of iron, it is obviou modified by the small differences in t carbon they contain: cast-iron resis strain; wrought-iron resists torsion; a tensile strain. The ultimate breaking the elastic resistance to stress by defle wise, are material elements of conside

fety—that is, the proportion of the ulti-
;th to the safe-working strain—depends
kind of strain the material is subject to.
quiet dead weight, and there is a sharp
ht. Steel is preferable for resisting the
s, and wrought-iron for the latter.
ll its forms—cast-iron, wrought-iron, and
de up of minute particles or atoms, and
n is limited. Bend the material beyond
limit, and it is damaged—either bent or
it, so long as the working strain does not
disturb the arrangement of the atoms, the
es its original position—without fracture
damage—when the load is removed.
ngth necessary to break a bar of steel,
n, or cast-iron, one inch square, has been
by careful experiment, from the results of
working-load is fixed. A wide margin of
lowed, not only for the sake of security
inary circumstances, but to insure the
against the effects of unforeseen accidents.
am of an engine is broken in halves by the
d by water present in the cylinder, the
n all probability show a flaw hitherto hidden
f the cylinder be flooded with water through
ss, so that the wide margin for safety in the
the beam may be exceeded, no flaw may
ed.

erefore assumed that, in the designing of
e first and foremost consideration is the pro-
ufficient strength and power of resistance in
. But there is this point to be observed:
e to be on the right side to the verge of

absurdity. An amusing volume co
the extremes to which engine-buil
have no data as regards the safe-work
and other materials to guide them in d
mill-gearing, and machinery.

If one speaks of an engineer as an
the description may appear advanced.
the potter, an artist? Everybody w
knows anything of his best ware; bu
be applied in a limited sense, since he
any original work. For all that he w
differed materially from such a potter
Robbia, who applied his own art inte
living religion of his day. Wedgwood
from the antique, and allowed his em
the interpretation of an ancient myth
he allowed no bad imitations to be ma
was the admiration of form.

Now there is no finer field for t
what is admirable in *form* than in t
beam-engine, and the house in which
are not infected yet with its artistic
time will come when the age of engin
make many an old engine-designer's
he of course will deplore the degen
engineers.

What should prevent the influence
entering the engine-house? All the
comparatively done, and there re
imitate and develop the beautiful i
done to a considerable extent.

The engine-builder is an artist. I
to turn out the most satisfactory pro

for fineness, for durability of fabric, for perfection of execution.

The use of steel and the practice of case-hardening are evidence of the desire to combine strength and durability in a satisfactory form—ornamental.

The parts of an engine generally case-hardened are small, but subject to great friction, such as the slide-link, the slide-block, bolts, and excentric-rod eyes. Case-hardening is a process for converting the surface of iron into steel. There is a defective as well as perfect process. The defective process in case-hardening is to expose the articles necessary to be carburized with a *scale* on their surface. The scale varies in thickness, and is a bad conductor of heat. It does not signify what it is—whether a link or a razor—if it is not thoroughly clean and bright it will not harden properly.

When a large quantity of parts of engines made of iron are to be case-hardened, the faces to be steeled are polished, the whole is put into a sheet-iron box and covered with articles of a carbonaceous nature, such as bones and horn, from which the ammonia and other irrelevant elements have been driven off by distillation.

If the bones or other material are ground to a powder to be equally distributed, the articles can be better operated upon and more effectually steeled than if they are laid in coarse pieces.

The box having been made air-tight, it is exposed to a very high temperature, at a red heat, for at least twelve hours for articles of moderate size. The exposed surface of the pieces will have been changed from iron to steel, having absorbed a sufficient quantity of carbon. After the box is withdrawn from the furnace,

its contents are turned out into a bath
of water and oil. The articles are
oil from being cracked in cooling.

The surfaces of the articles not
hardened should be covered with c
viously to being enclosed. The steel
taken out of the water or oil, being h
difficult to make an impression upon t
therefore they are brightened with f
the working surfaces, and they are g
working surface. By this means a
steel is formed on the working su
iron.

Steel, after it is finished, either
the vice, can be tempered or harden
of tempering is different from that
of iron. To temper steel, it is h
degrees of temperature for differe
engine-bushes, and crank-pins, an
pieces, the steel, when it has attainec
ness, is immersed in water or in oil su
drawn almost immediately. The ten
appear, and so soon as a pale-straw t
piece is again plunged into the liquid
degree of hardness is obtained.

The following are some of the colo
tempering of steel is regulated:—V
for lancets; pale straw, for razors a
faces; a full yellow, for pen-knives; l
brown with purple spots, for axes
purple, for table-knives; bright blue,
and bell-springs; full blue, for fine
nearly black, for hand saws. Tempe

.uces a soft bending steel, so that the teeth of a can be either filed up or set, and yet be suffi- :ly hardened to cut wood.

nnealing is a process the reverse of case-harden- The articles operated upon are converted from a tion of brittleness to a condition of comparative ιness. The process is employed in order to file, re-turn in the lathe, any portion of an engine ιas been previously hardened. In the annealing el or iron the metal is heated to a low redness, lowed to cool gradually. The operation is per- l not only to soften the article, but also to restore ticity.

hould also be mentioned that, whilst in a soft on, wrought-iron, steel, and copper can be under the hammer into any required form; process of welding, which means the joining of ces of metal together, is only applicable to iron steel. Heated to a white heat, iron and iron velded together; so also can iron and steel be together; but the steel must not be over- therwise it will burn.

gun-metal, and white-metal are all alloys. n alloy designates a combination of two or tals, having a chemical attraction to cause ιdhere to each other. As previously stated e made up of atoms. When atoms of the l hold together, that is cohesion; but when ι different kind join or hold together, it is mical attraction. One atom of copper is another of copper by *cohesion;* but when an pper unites with an atom of zinc, it is an chemical *attraction*, or, as it is sometimes

called, chemical affinity. Chemical attraction is distinguished into three degrees—namely, mixture, solution, and chemical union.

Chemical *mixture* takes place when the atoms of two bodies are in a liquid state, and have freedom of motion between themselves, upon which fluidity depends. A crucible containing molten metal, such as brass, zinc, and tin, contains a chemical mixture.

Chemical *solution* operates between solids and liquids. A glass containing water with a piece of sugar dissolved in it contains a chemical solution.

The power of solution is limited, as liquids cannot combine with more than a certain quantity of solid matter. When the point of limitation is attained it is called the *point* of *saturation.*

It is worthy of notice, that when water has dissolved saltpetre up to the point of saturation, it will dissolve a considerable quantity of common salt. How is that?

Here is a basket full of tomtits' eggs, which represent the globules of water; into the basket of eggs we can put peas until it will hold no more; we, however, put in some corn until it will hold no more of that; but even then we can add mustard seed, and the basket will be no fuller than it was at first.

So it is with water holding in solution other matter.

The highest result of chemical attraction is union, which may take place between bodies under every modification of cohesive attraction.

Bodies that unite in this manner combine only in fixed proportions, and the combination will often produce a total change in the properties of the combining substances, and produce heat. Combustion of coal, to wit.

On the application of a certain amount of heat to coal, gas is generated, which forms a union with the air; but if the latter is deficient in quantity the result is water. Why? The *gas* is hydrogen, the *air* contains oxygen, and the two, in fixed proportions, form the water which fills our rivers and brooks, in which fish swim and dive, and dive and swim. If we add a little more air—another atom—the result is carbonic acid.

Suppose the air to be supplied to a furnace so that no smoke is visible, we should say the *proper quantity* of air was being admitted into the furnace rendering combustion perfect, and evolving heat; and when that is so, chemical union is in the highest degree accomplished.

We were referring to alloys, and having explained the term, with other matter more or less intimately connected with the subject immediately before us, we can now turn to the crucible pots, and after taking the lid off look into them.

The first contains an alloy for brass, which consists of—

$$\left.\begin{array}{l}\text{9 parts of zinc}\\ \text{16 parts of copper}\end{array}\right\}\text{Brass.}$$

Brass is a very common alloy, and is not used much about engines.

The next pot contains an alloy for gun-metal, which consists of—

$$\left.\begin{array}{l}\text{9 lbs. of copper}\\ \text{1 lb. of tin}\end{array}\right\}\text{Gun-metal.}$$

Gun-metal is very extensively used for bearings and bushes.

The next pot contains an alloy for white-m which consists of—

2 lbs. of antimony 8 ozs. of brass 10 ozs. of zinc	} White-metal.

White-metal is used on account of its softness, renders it deficient to support a weight of itsel it is therefore applied mechanically to a bear various ways.

Sometimes a row of holes, drilled in a zig-zag in the crown of a bearing, are filled up with metal. This is done to reduce the friction to mum. It must be understood that there is no thing as a *perfectly* smooth surface. We tur and bore out a brass as true and as perfect as how to do; but, as seen through a micro contiguous surfaces are as rough as a "bea and as hard as "flint." By drilling a d or more the area of this hard and rough reduced, and by filling them up with softer siderable resistance is removed. In fact son will not run cool unless filled up with white.

It is very necessary to obviate heat by machinery, which may be produced when and put together with all its parts duly and fitted together, with no side or end play. Now all metals expand by heat, whether fire or by friction. Allowance for this of caloric, common to all bodies whatever considerable attention of late years; but was literally ignored, and the cost has Nature will have her course. If man about, he soon finds her paths are plain.

But if he puts up a large brass, cottered tight-up, and neglects to allow room for expansion by heat, he will find that the brass will make his ways far from pleasant.

It should be remembered that there are parts of an engine which must necessarily expand. If an engine-man duly considers this, it will *guide him in many* instances towards a right issue. *Nothing either in* the engine or the boiler is of the same size when cold as it is when hot. Therefore, instead of *this principle* being thought lightly of, it should command very great consideration. I know a case in which *the con-*nection between two boilers in steam was torn asunder through the allowance for expansion being neglected. Another case was that of a large valve being fitted too tightly into the bridle when cold; so that the valve broke the bridle by over-expansion. Sometimes we see packing being driven into a stuffing-box, with the aid of a hammer and chisel; consequently, when it is heated by steam, the rod is gripped as by a pair of clamps, as a result of expansion. Lubrication becomes impossible.

Further, sudden expansion by heat, it should be remembered, is often attended by serious consequences. Many a cylinder-condenser has thus been cracked. Many a boiler has been started leaking. Sudden expansion has made many an employer's heart and head che, and brought remorse to the engineman.

Heat travels from point to point in various ways, ich may be graphically explained—thus. If we ke a fire in the bars within a Cornish or any other ription of boiler containing water, a portion of the from the fire is communicated to the crown-plate

by *radiation* from the surface of the f
through the iron from the inside of th
outside of the plate, and into the water
It passes from the surface of the fire in t
rise from the fire, upwards and onwarc
flues, by *convection*. It passes through
boiler-shell by radiation into the boi
house.

Conduction.—If a piece of iron he
suspended against an iron column, th
ducted into the column. Or, if a bar c
at one end the heat will travel along t
the cooler parts. Conduction means
through matter, from places at a hig
to places at a lower temperature; or it
to be the transfer of heat between the
or between two bodies which touch ea
distinguished as internal and externa
cording as it takes place between the
tinuous body, or through the surfaces
distinct bodies. The rapidity of int
is very much greater than that of ext
Bodies conduct heat with different de
hence some are good, and others are
Taking the conducting power of
that of copper is 89; of iron, 37; of
brick-earth, 1.

Wood possesses but little conduc
end of a stick can be held for som
other end is burning. Its inferior
is taken advantage of when wood is
handles of cocks and for "cleading,"
Bodies of a porous nature—wood

ecially fibrous substances, as wool, are extremely conductors. When an engineman is thoroughly uainted with the conducting power of substances, learns on what substance to bed and surround the lers, so that the least possible heat may be con- ted from them.

Conduction may be defined, in short, as a giving *out* heat.

Metals are good conductors of heat, and therefore d radiators—giving off heat to the surrounding dium. To prevent the loss of heat in this manner m steam-cylinders and steam-pipes and the tops of lers, they are clad with felt or with wood; or, in case of boiler-tops, covered with burnt earth, such lisused fire-bricks ground up into small pieces.

Water is a bad conductor of heat. When steam is t raised in a boiler, the hand may be applied to the er part, although the temperature of the water be)° or 250° at the upper part. It is because of the -conducting character of water that heat is ap- ed to boilers as near as possible to the bottoms of m.

Convection is the carrying of heat. The water in a ler is heated by the hot particles immediately in tact with the hot-plates rising to the top of the ter with the heat imparted to them by conduction. en the heat enters a part of the water, the water ands, and therefore it becomes lighter than the er stratum of water near the top, or even just above This change in its specific gravity or weight, in portion to its bulk or volume, causes the heavier tions to displace it; and by a successive displace- t it is eventually lifted to the surface of the

water. The act of boiling creates a current of hot globules upwards, expanded and charged with heat taken from the furnace-plate; and a current of cooler globules descending to absorb, in their turn, and to diminish the quantity of heat applied to the plate by the fire in the furnace. It is clear that if the globules of water are embarrassed in ascending or descending conduction is hindered, and the plate is liable to be damaged by overheating. Evaporation depends for its efficiency not altogether on the quantity of heat applied to the plate, but also upon the quantity of heat taken from it by ascending and descending particles of water. Hence the necessity for favourable circulation, and the absence of overcrowded flue-tubes.

Again, the heat from the walls of the steam-cylinder is conveyed to the condenser by convection.

Radiation.—Steam-pipes radiate heat into the surrounding atmosphere or the enclosing walls. How can this loss be prevented? By clothing the hot surfaces with non-radiating substances, as already mentioned. It is highly probable that the characteristic of non-radiation is due to the presence of confined air among the interstices of the substance or material; as air is a bad conductor of heat, and offers a barrier to the escape of caloric.

CHAPTER III.

THE STATIONARY ENGINE—CONDENSING BEAM ENGINE.

PLATE I.—A is the cylinder, securely bolted to the base-frame J 2, placed inside the outer casing or steam-jacket B 2.

B is the valve or nozzle ; C the cylindrical slide-valve, by which the admission of steam to the cylinder is regulated, as well as the exhaust to the condenser. A 1 is the upper steam-port ; A 2 is the lower steam-port ; B 1 is the throttle-valve in the steam-pipe. It is here shown in the position it occupies for convenience ; but it is usually placed close to the nozzle. D is the piston, to which the piston-rod E is attached by means of the conically formed end, and the nut E 1. The piston-rod passes through the stuffing-box A 3, and the upper end is fixed to the middle cross-head E 2. F, the main-links of the parallel-motion connecting the cross-head to the cylinder-gudgeon at the end of the working-beam or main-lever G. The parallel-motion consists of the main-links F, the back-links F 1, the parallel-rods F 2, and the radius-rods F 3. There is a complete set of this motion on each side of the main-lever or beam. The parallel-rods connect the cross-

head E 2 at the lower ends of th
cross-head F 4 at the lower ends o
The radius-rods connect the cro
ends of the back-links, to the stuc
H is the spring-beam to whic
porting the studs are secured. T
air-pump-rod Q 1 is fixed to th
Q 2. The back-links connect th
gudgeon Q 3, fixed in the main-le
The function of the parallel-m
piston-rod and the air-pump-r
lines of ascent and descent, thi
strains which would, if they we
upon them when at work, arisi
motion of the end of the beam.
The centre or main gudgeon o
lever oscillates, is supported by
blocks," one on each side of t
are bolted to the spring-beam a
beneath the spring-beams. Th
the spring-beam under the ma
of the spring-beam are secured t
The extremities of these girder
ture, are built into the walls of t
The entablature is further sup
J 1, one under each main plumm
The upper ends of the colum
the entablature; and the lower e
J 2. The base-frame is secured
to the foundation.
The gudgeon at the other e
lever, is connected by the con
crank-pin K 1, fixed in the end c

The crank-shaft L, to the end of which the crank is firmly keyed, is supported by and revolves in the bearing L 1, bolted to the base-frame.

The fly-wheel L 2, and the excentric M—shown on the drawing in dotted lines—are likewise keyed to the crank-shaft M 1. The excentric-rod connects the excentric to the lever M 2. Levers, N 1, are placed on the same shaft, at right angles to the lever M 2, one on each side of the slide-case.

N the rocking-shaft or weigh-shaft, on which the levers N 1 and M 2 are keyed.

The side-links C 3 connect the ends of the levers N, 1, to the cross-bar C 2, on the slide-spindle.

The slide-valve rod or link, C 1, is fixed at the lower end to this cross-bar, and at the upper end to the slide—valve.

N 2 is the balance-weight, fixed on the back end of the lever N 1, to balance the weight of the slide-valve and the rods. O 1 is the exhaust-pipe leading to the condenser O. O 2 is the injection-sluice, by which the injection-water for condensing the steam is admitted, as a jet, and the amount regulated. O 3 is the passage from the condenser to the air-pump P. P 1 are the suction-valves; P 2 the delivery-valves; Q the air-pump-bucket, provided with valves. Q 1 the air-pump-rod, fixed at the lower end to the bucket, and at the upper end to the middle of the cross-head Q 2, as already mentioned. R is the hot-well; S the cold-water cistern, in which the condenser and the air-pump stand, surrounded by water. S 1 the overflow-pipe for waste water. T is the cold water pump; T 1 the suction-valve; and U the pump-bucket, also supplied with a valve. V the rod connecting the bucket

to the gudgeon V 2, fixed in the main-lever; T 2 the delivery-pipe to the cold-water cistern. V the feed-pump; W, the plunger, connected to the gudgeon W 2 in the main-lever by the rod W 1. V 1 is the suction-pipe from the hot-well. V 2 the delivery-pipe to boilers. X the standard supporting the governor. X 1 is the governor-spindle, on the lower end of which is keyed a bevil-pinion worked by a bevil-wheel fixed on the shaft; X 2 is the fulcrum at the upper end of the spindle for the arms or bell-crank levers X 3. The governor-balls X 4 are fixed to the extremities of the lower arms. The ends of the upper arms are connected by the links Y 1 to the sliding-brass Y. The rod Y 3 is attached at the lower end to the sliding-brass by the swivel-joint Y 2; and is connected at the upper end to the bell-crank lever Z.

The rod Z 2 connects the lower arms of the bell-crank levers Z and Z 1. The other arm of the bell-crank lever Z 1 is connected by the rod Z 3 to the end of a lever fixed on the throttle-valve spindle. To this spindle the throttle-valve B 1 is also fixed.

The working of the engine is as follows:—To start the engine, the first operation is to get rid of all the air and water in the cylinder and steam-passages, and to warm the cylinder by admitting steam to the jacket B 2. This is effected by blowing through a quantity of steam into the condenser. The steam is condensed and a vacuum is produced at one side of the piston; whilst steam is admitted to the other side.

These operations are carried out by working the hand-lever M 3, fitted to the lever M 2 on the weigh-shaft; the excentric-rod M 1 being meanwhile disconnected. The slide-valve is then moved alternately up

and down, in order to distribute the steam to the upper side and the under side of the piston. By this operation the engine is set in motion. The end of the excentric-rod M 1 is then thrown into gear by connecting it to the lever M 2 by hand. The slide-valve is kept in motion by the excentric M on the crank-shaft. The excentric is a circular disc, so formed and placed on the crank-shaft, that the centre of the disc is at a given distance from the centre of the shaft, and revolves about it. The periphery, or outer edge of the excentric, is grooved, and the excentric-rod is connected to it by means of a ring or excentric-strap, as *it is* termed, fitting into the groove. The excentric-*strap* is made in halves, bolted together; one half being secured to the excentric-rod.

By this arrangement the strap is easily placed upon, and maintained on, the excentric; and whilst it embraces the excentric, it admits of the excentric revolving within it.

The result of this combination is that, whilst the excentric revolves with the shaft, a reciprocal lateral motion is imparted to the excentric-rod, and to the end of the lever M 2 to which it is connected, the extent of the reciprocating movement being equal to double the distance between the centre of the crank-shaft and that of the excentric. This distance apart of the centres is termed the throw of the excentric.

As the levers M 2 and N 1 are of equal lengths, and both are keyed to the weigh-shaft, the end of lever N 1 moves through a space equal to that traversed by M 2. The same motion is transmitted through the *links* O 3, and the slide-valve-rods to the slide-valve.

The shaft, in continual rotation, causes also *the*

excentric to revolve; and the horizont
the excentric is communicated to th
which in its turn, by means of the l
imparts a reciprocating movement, thou
direction, to the slide-valve; the exten
communicated to the valve being equa
traverse of the excentric, or to twice the
preliminaries being understood, the n
working of the engine may now be consi

Starting the Engine.—Let the engine l
tion where the piston has described one
descending stroke. By the mechanism j
the slide-valve is placed in such a posi
upper steam-port is left open to the ste
boilers, which enters through the throt
the slide-case to the cylinder, and forc
downwards.

The lower steam-port is open to the
the steam which was admitted to the lowe
cylinder, and by which the previous up
made, has passed out and down the exha
tion-pipe to the condenser. There it meets
injection-water supplied from the cistern.

The water is forced into the condenser th
injection-pipe and sluices by the pressure of
sphere. The steam, as it comes into contac
cold water, is instantly condensed, and a
formed in the condenser, and in the cylinder
piston. The water employed for condensing
and the condensed steam itself, occupies the l
of the condenser, until it is pumped out by
pump.

The steam is prevented from leaking past

by the packing-ring D 1, which is kept in its place by the ring D 2 secured to the piston. The packing-ring is forced out against the cylinder by means of springs fitted in the space within the piston, at the back of the spring.

As the piston and its rod descend, the end G 2 of the main-lever is also depressed, and at the same time the air-pump bucket is forced down by means of the air-pump rod.

The water occupying the lower part of the pump, which by the previous up-stroke had been drawn from the condenser, is prevented from returning by the valves P 1, which are now closed. As the bucket descends into the water the bucket-valves, which open upwards, allow the water to pass to the upper side; when the bucket arrives at the bottom of the stroke the valves are closed, and they prevent the return of the water to the lower part of the pump.

As the main-lever oscillates on the centre G 1, the depression of the end G 2 causes the opposite end to rise; and by means of the connecting-rod the crank K 2 is pulled up towards the highest point of its revolution.

The bucket of the cold-water pump is also being raised by the rod connecting it to the gudgeon V 2, delivering the water above the bucket into the cold-water cistern, through the pipe T 2.

The water is, at the same time, drawn into the pump through the suction-pipe and the open suction-valve T 1. When the bucket reaches the top of its stroke, the valve T 1 closes.

At the same time the feed-pump-plunger is raised the rod connecting it to the gudgeon W 2.

The delivery-valve W 4 is closed, and the water is drawn in from the hot-well, through the suction-pipe and open suction-valve W 3. This valve will also close when the plunger reaches the top of its stroke. As the piston nears the bottom of the down-stroke in the cylinder, the altered position of the slide-valve opens the upper part to the exhaust. The steam immediately rushes out of the cylinder, and down the middle of the slide-valve and exhaust-pipe, to the condenser, where, meeting as before the injection-water, it is condensed —forming a vacuum in communication with the upper side of the piston. By the continued movement of the slide-valve, it gradually opens the lower part to the steam from the boiler, and enters the cylinder under the piston. The piston is then forced upwards.

The end G 2 of the main-lever is also forced up, and with it the air-pump bucket is raised.

Air and water are thus drawn from the condenser through the suction-valves into the air-pump, and they are prevented from returning by the closing of the valves.

The water above the bucket is forced through the delivery-valves P 2 to the hot-well. The supply of feed water for the boilers is drawn from the hot-well by the feed-pump.

The waste water overflows through the waste-pipe R 1. The end G 3 of the main-lever is now depressed, and with it also the cold-water pump-bucket, and feed-pump plunger.

The suction-valve of the cold-water pump being now closed, as the bucket descends, the water in the pump passes through the bucket-valve to the upper side, ready to be delivered to the cistern by the next up-

stroke. The suction-valve of the feed-pump also being closed, the descending plunger forces the water now in the pump through the delivery-valve to the air-vessel v 3, whence it is conducted through the delivery-pipe to the boilers.

The use of the air-vessel is to form a cushion of air, the elasticity of which prevents or modifies the sudden impulses or shocks which would otherwise be given to the pump and its parts by the inelastic movements of water, which is incompressible.

The depression of the end G 3 of the main-lever causes the depression of the connecting-rod, forcing down the crank-pin towards its lowest point.

By the movement of the engine, the position of the slide-valve is again changed; and, as the piston nears the upper end of the up-stroke, the lower steam-port is again opened to the exhaust, and the steam passes to the condenser, as before. The upper steam-port is then opened to the steam from the boilers, and the piston is again forced down.

For each revolution of the crank-shaft there are two positions of the crank, called the dead points, at which the power of the engine exerted through the connecting-rod has no influence in causing revolving motion.

The dead points are those at which the crank-pin is at the highest and lowest positions of its revolution (1 and 2, Fig. 1, page 46).

When the crank is at the highest and lowest positions, the force of the steam on the piston is exerted in simply pulling or pushing the crank-shaft upwards or downwards.

To compensate for this characteristic of the action

of a crank, the fly-wheel, which is keyed to the crank-shaft, comes into play. By the momentum acquired by the fly-wheel during the intermediate portions of each revolution, when the crank is taking up the power of the engine, the crank is carried past the dead points; and thus from the up-and-down motion of the connecting-rod the continuous circular motion of the crank is obtained, and the shaft is made to rotate.

By the momentum of the fly-wheel also the engine is caused to work more equally and more smoothly than it could possibly work without such co-operation.

The use of the governor is to maintain the engine at a regular speed, and to proportion the quantity of steam used to the work which is to be performed.

The principle of centrifugal force is here applied. When the engine goes too fast, the rapid rotation of the shaft is communicated to the spindle of the governor and to the balls by means of the bevil-gearing.

The centrifugal force thus generated causes the balls to fly outwards and the upper arms or levers to rise. The brass-slide Y is thus forced up, and the movement is transmitted through the rods and bell-crank levers (as indicated in the drawing) to the throttle-valve, by which it is partly closed.

The quantity of steam admitted being thus reduced, the too rapid speed of the engine is checked and reduced. Conversely, if the engine is moving more slowly than when at its regular speed, the velocity of the governor is lessened and the balls fall. By the fall of the balls the brass-slide is pulled down and the throttle-valve is farther opened; more steam is thus

admitted to the engine, and its speed is brought up to the proper rate.

Steam is not admitted into the cylinder during the whole of the stroke of the piston; on the contrary, the slide-valve is closed, and the supply of steam is cut off to the cylinder before the stroke of the piston is completed. The enclosed body of steam expands as the piston moves on to the end of the stroke, and fills the cylinder. But the pressure of the expanding steam decreases as the space into which it expands increases.

This is the principle of the expansive-working of steam-engines. The practice of expansive-working to a greater or less degree is universal, and it is a means of effecting economy of fuel to a considerable extent.

Though the maximum available power of an engine may be reduced by the practice of expansive-working, yet, on the other hand, if steam from the boiler were to follow the piston right to the end of the stroke, the engine would not pass the dead points so smoothly as when it is cut off short of the end of the stroke; and, besides, the exhaust-passage would become choked with steam, and the final result would be a considerable degree of back-pressure.

Thus, if the steam is cut off at one-third of the stroke, the remaining two-thirds of the cylinder-space is reserved for the expansion of the steam lodged in the first third part.

It is found in practice that steam is saved in greater proportion than the power is reduced. Hence the conomy of the principle.

A certain quantity of power is really gained, for it l be evident on consideration that although the

Plate 1

r h
the

pressure by which the piston is impelled by steam worked expansively is gradually decreased as the volume of the steam in the cylinder increases, all the power given out by expansive action is obtained without the expenditure of any additional steam, and without any additional expenditure of fuel. On the expansive principle, steam of a higher pressure is used than is ordinarily the case in condensing steam-engines, where a low degree of expansion only is carried out.

CHAPTER IV.

DETAILS OF THE STATIONARY ENGINE.—CONDENSING BEAM ENGINE.

ALTHOUGH the "key" to the engine embraces as a ready reference a general view of its parts, yet only a cursory knowledge of the details can be obtained from it. The practical information which the engineman seeks can only be given by another process—namely, by applying to each detail a due amount of explanation, so as to give the why and the wherefore of each.

While it may be sufficient for one man to know that the steam is let into the cylinder by the slide-valve, another requires to know the benefits of lap and lead—the properties of the slide-valve. One man may be satisfied with nothing short of knowing how to test valves, and in fact not satisfied at all until he can see *through* the engine as plain as he can see his face in a glass.

Crank, K 2. (Plate I.).—If claims to the glory of first suggestions or of original invention are to be rigorously insisted upon, then the name of Jonathan Hulls must be made mention of. The crank motion, of which he was the patentee, is alone sufficient to immortalise his name amongst mechanics. A considerable time elapsed after the invention of the engine before a crank was em-

ployed to produce a rotatory movement from the reciprocating action of the engine beam. It is a remarkable fact that whilst much talent and ingenuity were being employed to find out a plan which should convert a rectilinear motion into a circular motion, and so utilise the engine for driving machinery as well as for pumping water, the means were nigh at hand, even in the street, to be seen in the knife-grinder's wheel. But where a rotatory motion is to be obtained from a reciprocating one, by means of the crank, a fly-wheel, L 2, is necessary to continue the motion at those two points of the revolution, called the dead points, in which the crank lies in the direction in which the moving force acts, for at the dead points the crank affords no leverage to the power, and consequently no power can be effectively exerted. When a force is alternately applied suddenly to a body, and ceases to act, it is an intermittent force. Such is the nature of the action of the steam on a crank through the connecting-rod which ceases to impel the crank at the dead points. With the aid of a fly-wheel on the crank-shaft, after a few revolutions momemtum is acquired sufficient to carry the crank past the dead centres, and to urge it forward in the direction of its circular motion until it is brought into a position again to offer leverage for the steam acting through the connecting-rod. When steam is urging the piston it is urging the crank; when its power ceases on the piston it ceases on the crank, and the augmentations and the diminutions of the power thus exerted, which follow each other rapidly, are by the momentum of the fly-wheel as a reservoir of force, converted into equable and regular action. But at every revolution of the crank

and fly-wheel, the heavy piston and the massive beam with its appendages have to be twice reversed in their motion; and were these reversals to be suddenly effected the engine-house would soon come down.

The shock at the reversal of the motion is prevented by means of the crank. Let *a b*, Fig. 1, represent the crank, equal to half the length of the piston stroke 1 2, or half *d f*, and let *d c a c f* represent the semicircle through which the crank travels whilst the piston performs a stroke, 1 to 2; then, with lines drawn from the stroke line to the crank-path line, it will be seen that the piston travels from *b* to *g* nearly at the same speed as the crank, and in the same time as the crank travels from *a* to *c*. But let us regard the next and finishing part of the performance: whilst the crank moves through the space *c* to *d*, the piston moves from *g* to *d*, only half the distance, and therefore at half the speed, and so the piston is checked and slowered in its speed as it nears the ends of the cylinders, and the shock which otherwise would have occurred is avoided.

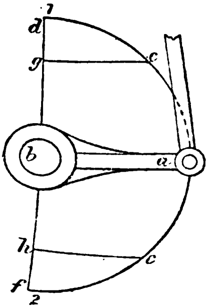

Fig. 1.

Link-motion.—The link motion is not fitted to all engines, as in some cases it would be superfluous, and would only increase the number of working parts of the engine. Any saving of fuel that might be effected by it would not atone for the expense of making it and keeping it in order.

The principle of expansion can be attained, with sufficient economical results in some cases, by means of

the lap on the *slide-valve*, indepen
expansion-valve, which is someti
steam off at any required portion

Therefore the link-motion is n
to obtain expansion. Some your
to think if an engine is without t
ing without expanding the stear
steam is generally, in engines no
cut off at one-third of the stroke
Practical considerations form th
"cut-off," but in cases where th
is uniform, there is no reason w
not be uniform also. The same
apply to an engine whose piston
loads, especially where expediti
quired, and varying loads and s
Then the expansion gear is empl
as the steam can be allowed to
nearly the end of the stroke,
quickly, or it can be cut-off
stroke.

The link-motion is also emplo
reversing engines. It consists c
their respective rods attached to
is frequently formed to a radiu
of the rods.

The link is made open; a "c
connection with the valve, may
by shifting *the link*. The hor
link is communicated to the val
the excentrics. When the die is
the travel of the valve is reduc
equal to twice the linear advanc

excentric moves the top of the link one way, whilst the other excentric moves it the other way, so that the reciprocating motion at the centre is just as much one way as the other, and if steam were turned on it would have no effect in moving the engine when the valve has not sufficient travel to uncover the ports. But by lowering the link the amount of travel is increased; and, when the link is lowered to the full extent, the valve receives its maximum travel; the excentric-rod occupying a position as nearly as practicable in a straight line with the valve-spindle. Thus the amount of travel which is communicated to the valve depends upon the distance at which the movable block may be from the central point in the link. By moving the "die" up and down in the link—which is, in effect, the same as the lowering or raising of the link on the die—the amount of travel of the valve may be varied; and seeing that the travel of the valve is the measure of the lap, to reduce the travel by raising the link is equivalent to increasing the lap, and hence it is that the link-motion derives its advantage in being able to regulate the amount of expansion, so that the steam can be measured out to suit the load upon the piston.

Parallel-motion, F.—The object of the parallel-motion is to provide for the rectilinear motion of the piston-rod, and to counteract the oblique push from the end of the beam. As the beam in all beam engines vibrates upon a centre, the end of it describes a portion of a circle over the piston-rod. The piston-rod, on the contrary, is bound to move up and down in a right line; it cannot, therefore, be directly attached to the end of the beam, and hence the intervention of the elegant mechanism called the parallel-motion, by means

of which the alternating recti
is made to work harmonious
curvilinear motion of a rock
consists of the main-links F,
parallel-rods F 2, and the radiu
rods connect the cross-head E
the main-links to the cross-hea
of the back-links. The radius
head at the lower ends of the
or centres H 2 on brackets by t
rod.

The principle of the motion
motion of the end of the para
fined by the motion of the end of
point E 2 as to cause it to descr
doing so it maintains the alternati
of the piston in the same path.

Governor.—The application of
mechanism for governing the supp
cylinder was made by Watt. The
invented by him: in his day it was
corn-mills, which, from the days of t
been the nursery of engineering skil
superior millwrighting. The great n
lating the speed of the stones so that
force should not exceed the centripetal
brilliant thought occurred to him that i
for governing the speed of the steam-
desirable object to be effected, since eng
to "race," with the contingency of br
selves to pieces. It is not by any means
rence for a fly-wheel, or a part of a fly-w
through the wall of an engine-house in co

the engine not being well under the control of the governor. All forces act in right lines, and when a mass of iron is moving in a circle it has a tendency to fly off in a right line, forming a tangent to the circle of motion. This tendency may be simply exemplified by whirling round a can of water or a weight by means of a string. As the speed of revolution is accelerated it is found necessary to hold the string more and more tightly. Now the force which pulls the string is the centrifugal force, and when this force is alarmingly increased, in the case of an engine running off too fast, the danger is that the fly-wheel will burst and fly to pieces, the centripetal force due to the cohesion of the metal keeping it together having been exceeded by the centrifugal foree. Now the engine governor is specially adapted to keep the speed below such a dangerous point. When the engine is in motion, the motion of the shaft, on which the fly-wheel is keyed, is communicated to the governor-spindle X 1, at the lower end of which is a bevil-pinion worked by a bevil-wheel fixed on the shaft.

The centrifugal force thus generated in the governor-balls causes them to fly outwards and the levers to rise. The brass-slider Y is forced upwards, and the connecting-links Y 1 brought downwards.

This vertical movement is transmitted, through the rods Y 3, which are lowered, to the bell-crank lever Z; and thence through the rod Z 2, by which the lower arms of the bell-crank lever are connected to Z 1, the other arm of the bell-crank lever. Z 1 is connected by the rod Z 3 to the end of a lever fixed on the throttle-valve-spindle, and to this spindle is attached the throttle-valve B 1, which is open when the engine is at

rest, and the opening
is increased. Wher
the regulated speed
and in the manner
off and the speed re

Piston, D.—There
requires to be mor
the piston. It co
cast-iron—strongly
tapered hole in the
conical end of the
the piston by mean
plate.

The piston-rod
check-plate and u
piston is warm, wh
in the piston. Th
fit the cylinder sc
without binding a
If it does not touc
the steam is admitte
blow through and w
piston, so neutralisin
face. If the piston w
it would rub hard a
and the friction thu
become too slack. St
the cylinder and the
surfaces. The piston
to retain the requis
time. For this re
for packing the pist
piston a recess, or a

to receive a steel spring, immediately outside of which is fitted a cast-iron ring, which is turned and finished a little greater in diameter than the cylinder, so that when it is cut through with a saw at one point, and the space made by the saw closed up by compressing the ring, it will then fit the cylinder accurately and not too tightly. Its tendency to spring out causes it to press against the sides of the cylinder, and thus it is that an elastic metallic ring prevents the steam blowing past the piston. This metallic ring is kept in its place by means of a junk ring applied to the outer face of the piston, and fastened by screws to the body of the piston, so adjusted as to allow the metallic ring freedom to work round in the recess, and force itself outward in all positions of the piston. If the junk ring happen to be screwed down so as to jam the metallic ring, then the steel spring underneath it is prevented from exercising its function of assisting to keep the metallic ring in uniform contact with the barrel of the cylinder.

Air-vessel, v 3.—This vessel is fitted on the delivery-pipe or the upper side of the pump-valve boxes. It is a contrivance for continuing the flow of water when the impelling force of the ram has ceased to act, or whilst the pump-ram is making the outdoor stroke. It thus keeps the discharge more nearly constant than it would be without the air-vessel. It also prevents the shocks which would arise from the sudden stoppage of the water whilst in motion, and obviates the loss of power which would be involved in stopping and starting the water from a state of rest at each stroke. With a single-acting pump, imagine that the discharge of water into the delivery-pipe is faster than it

can escape through the delivery-va
in the air-vessel which contains
compressed proportionately to th
trated upon the water. On the
ram, as it makes the outdoor str
the pump closing, the compressed
of the air-vessel expands and reac
of it, and continues to expel
pressure of the air becomes equal
of the column of water between t
mouth of the delivery-pipe. The
a sort of elastic cushion in the a
ises irregularities in the workin
pump works all the better wi
air-vessel takes the knock off t
takes place when the ram ma
and the water in the delivery-p
upon the valve or clack, forcin
with a rattle. But, as already
obviated by the action of th
keeps the water back and co
wards the boiler. In large pun
water in great quantities or
found imperative to form a r
vessel to counteract the irreg
in the mains. A special pun
pump air into the air-vessel
elastic power of the compre
by self-acting valves of the
kind, the shocks and irregu
in the mains are counteract

Valve-motion.—One of th
trivances for reversing th

steam into the engine was a four-way cock, which was used by Leupold a hundred years ago, but was invented by Papin many years before that time.

But it may be well to mention that, two hundred years ago, the piston was reversed by withdrawing the fire, when the steam was condensed by cooling the cylinder by the air from the outside. In the next stage of improvement the fire was retained, and the cooling of the cylinder, and the consequent condensation of steam, was effected by dashing cold water over the cylinder.

It appears very strange that our ancestors should have contrived to raise a piston and not at the same time discovered how to lower it with equal facility.

Following the plan of condensing the steam after it had lifted the piston to the top of the cylinder by cooling from the outside, means were used to cool the cylinder within by opening a cock and flooding the cylinder with water from a tank fixed above, so that the water could enter by the force of gravity. The steam having been condensed, and the contents of the cylinder run off, a vacuum was formed and, the top of the cylinder being open to the air, the pressure of the atmosphere on the face of the exposed piston lowered it to the bottom of the cylinder, and at the same time lifted a bucket full of water from the mine. The steam was again admitted by a *cock* to raise the piston, and by the same movement the empty bucket was lowered into the water. Thus, the lifting of the water, which was the work done, was not performed by steam, but, as already explained, by the atmospheric pressure, which pressed the piston into a vacuum beneath it. Hence it is that such engines were called atmospheric

engines. The pressure of the atmosphere is $14\frac{3}{4}$ lbs. per square inch, and with a piston having an area of 100 square inches 1,475 lbs. of water could be lifted from the mine to a height equal to the length of the cylinder. The elastic force of the steam was the first power, and the atmospheric pressure was the second power. The operation of working such an engine required constant attendance. If steam was admitted to the cylinder too long, the piston was sent out of doors into the fields; and if it was allowed to descend with its whole force to the bottom of the cylinder the chances were that the engineman would find himself up to his neck in scrap-iron.

The management, therefore, required constant supervision with sprightly action to make a fair number of strokes per hour. A fair day's work was done when fourteen strokes were made per minute.

This necessarily wearisome and constant watching of the piston became distasteful to a young engineman named Humphrey Potter, a "Staffordshire knot," and he concocted a catch applicable to the steam-cock, and which was moved by a piece of string attached to the beam, and made the engine comparatively self-acting. Humphrey was quite a lad, and this was done to allow him to do a little business amongst the "birdies," to look for a tomtit's nest in the stump of an old oak, or climb a fir-tree for a hatch of thrice-cocks.

This device of Potter's drew attention to the advantage of making the engine more nearly self-acting, and the incident gave rise to many and useful inventions which have since become incorporated in the valve-motion.

As time advanced, the gear was made up of "tumbling

bobs," "forked-legs," "centre-pins," "shanks," "spanners," "tooth-sectors," "snifting-valves," "valves" moving on a hinge. By manipulating these "crinkum-crankums" the speed of the engine was accelerated.

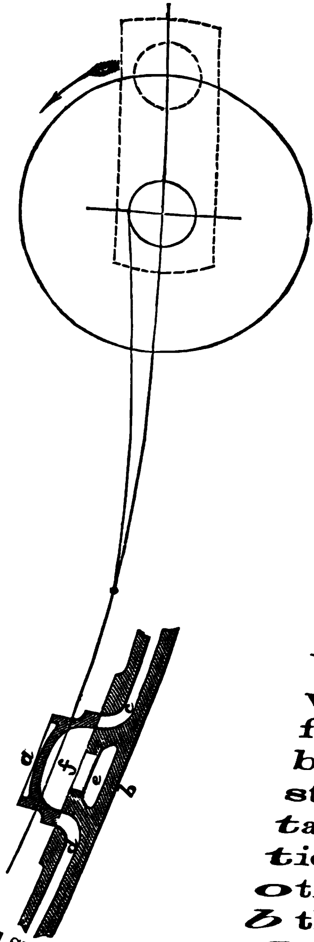

Fig. 2—Old Slide-valve.

The valves for admitting steam to the cylinder were either conical or flat-faced, worked by means of a chain or a catch attached to a lever suspended from the beam.

Later on, Watt worked the valves, which were conical, with tappets on the pump-rod, which, in ascending and descending, caught the lever attached to the valves, and therefore opened and shut them as required.

Murdoch, an assistant of Watt, invented the D-slide-valve and the excentric-gear for working it, illustrated by Fig. 2, which was a great stroke of engineering, and takes precedence in its adoption for general use before all other systems. *a* is the valve, *b* the cylinder, *c* the back-port, *d* the front-port, and *e* the exhaust-port; *f* the cavity of

the valve. It will be seen tha
valve just cover the ports lead
therefore a movement in either
the excentric would admit stea
cylinder. The piston is at the
the elastic power of the steam w
forces it down the cylinder. W
bottom the opposite port is ope
entering at that end, pushes the
the top; hence the motion of the
of the cylinder. The valve work
wards over the ports *a* and *c*; th
valve, when drawn towards *f*, let st
and, when they are drawn from *f*,
opened to the cavity of the valve,
in the centre of which the letter *f*
it is clear that the steam-ports *a* a
open to admit steam for working
same time; but, by means of this
soon as one port is opened, the othe
when the port is opened to the cavity
steam which pushed the piston to
cylinder can suddenly return, not into t
but into the chamber within the valve,
port *e*, either into the condenser or th
In Fig. 3 the steam-port *d* is shown op
haust-port. The valve is surrounded by
outside, waiting for the valve to move as
it to enter the cylinder; the valve inside i
exhaust to allow the steam to leave the cy
it always does when its elasticity is great
of the atmosphere. But it will exhaust in
with an elasticity less than that of the a

because a vacuum is emptiness, and the atmosphere is a reservoir of air, having resisting power of itself of $14\frac{3}{4}$ lbs., or as a round number 15 lbs., per square inch. The style of the valve, as given to the world by the ingenious Murdoch, is represented in Fig. 2, and there are, according to the results of modern practice, two defects about it. The first is want of lead, and the second is want of lap.

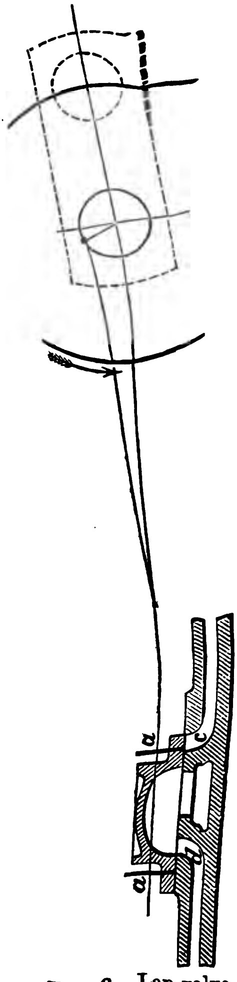

Fig. 3—Lap-valve.

What is Lead?—Lead is the amount of opening which the valve gives to the steam-port when the piston is at the beginning of a stroke. The opening of the port is given to enable the steam to fill up the steam-port and the clearance at the end of the cylinder, so that it may act as a cushion for the piston in completing a stroke, and to assist in reversing its motion easily, and without straining its connections. When the valve opens the port by $\frac{1}{8}$th of an inch in width before the piston arrives at the end of the cylinder, the valve is said to have $\frac{1}{8}$th of an inch of lead.

What is Lap?—Lap is shown on Fig. 3 at *a a*. This valve represents modern practice. If the pieces of the valve marked off by the line were taken away, it would be the same valve as Fig. 2, and it would just cover the ports in the same way.

Now, if a valve has $\frac{3}{4}$
pieces, *a a*, are $\frac{3}{4}$ths of
back and front, and t
width over the steam-
or $1\frac{1}{2}$ inches.

After the steam is cu
in the cylinder until th
of its lap, instead of
exhaust by the inner
period of this travel th
by its expansive force.
expansive-working m
longed; the steam ca
times, or it need not
for *outside* lap and le
lap and lead, though
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Inside lap is the am
of the slide-valve cover
is at half-stroke. The
escaping from the cyli
than when there is
expansive-working is p
carried too far it may
the release, and cause
then said to be wrapped

Inside lead is the amou
of the slide-valve is cle
sponding steam-port; or
of each steam-port to th
at half-stroke. It has a
inside lap, by causing a
the steam from the cylind

confined in the cylinder so long, it shortens, as a matter of course, the period of expansion.

Back-pressure is the counter-pressure on the piston at the side opposite to that on which the steam is at work. In a non-condensing engine, it is measured by the amount of pressure above the atmosphere, and may be caused by inside lap and contracted egress for the steam to clear the cylinder. When an engine exhausts into a vat at the bottom the back-pressure is enormous, unless the steam is released by a valve placed on the exhaust-pipe. Back-pressure in a condensing engine is the total amount of pressure on the opposite side of the piston, measured from the line of perfect vacuum. The pressure in the condenser is less than the back-pressure on the piston.

Condenser and its Appendages, O. (Plate I.)—During the dog-days of 1764, the professor of the class for Natural Philosophy of the University of Glasgow placed in the hands of Watt a model steam-engine to repair. What this incident led to would fill volumes to tell. Whilst engaged upon this model, speculation was active in his mind, enthusiasm spread its wings, and these potent influences urged him onwards and onwards, when he became the most enduring character in the history and progress of the steam-engine.

The engine was not the invention of any one individual; it was the outcome of the reflections, the taste, the observations, and the experience of many minds. The rude outline emanated from a brain having the capacity to conceive; its practical adaptation to a workable shape with a capacity to execute. The two faculties are not always co-existent in the same mind, and the palm of victory is carried off by that genius

who elaborates the idea,
such a way as shall dem
Such a genius was Wat
circumstances contracted
on his side, and he used
of his path. The immor
be very briefly given. W
sion he justly looked up
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powers.

Watt saw all its weak
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open at the top to the at
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ing cold water into the
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engines at this period
principle. His acute in
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piston. It was mental con
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The engineers of the day
ration for engine-build
reached beyond. He w
share of penetration, an
what benefit would his se
large had he simply me

metal, instead of scattering light where there was no light? He set himself to the task of solving the riddle, by which the engine had been cramped for years; and his strength of resolution rewarded him. Why, at this very time there were men living who had been baptized with steam, but he had divorced himself from the lifeless idea that that had anything to do with the form or direction of *his* life; and his philosophy admirably displayed what could be accomplished by genius.

To his task. *Scene:* A lonely room in the college. *Subject:* Loss of heat from the condensation of steam within the cylinder, by the injection of cold water, to produce a vacuum under the piston. *Note:* The mode of creating a vacuum by the injection of cold water *into* the cylinder itself was suggested by accident, which came about when water was used on the top of the piston to keep it steam-tight, and when the exhaust-steam—that is, the steam which had lifted the piston from the bottom to the top of the cylinder—was condensed by dashing cold water over the outside of the cylinder. A hole in the piston of an engine, through which cold water leaked, so increased the condensation of the steam as to be perceptible; and although at first the improved rate of condensation was ιot explained, and was attributed to other causes than he right one, yet when the true cause was discovered engaged attention, and provoked instant action. mple as it was, it was the means of conferring upon e steam-engine additional interest. It was very easy inject cold water into the cylinder, and to note its ›cts, and afterwards compare it with the external ιsh system. This is exactly what was done, and it

was, as we may now understand, emine
and the operation at once placed the en
fitted with an injection-water cock at a
there was a vast waste of steam, and th
without any appearance of healthy vit
being spasmodic and uncertain. To st
was necessary to blow steam into the
the lower side of the piston, until t
hot as boiling-water. By this operat
extracted from the steam, and taken u
of the cylinder and piston. These
charged with heat—being as hot as
cylinder was prepared for the opening
cock. The time for this to be don
steam blowing from the cylinder thr
valve attached to it, and which could o
the cold surfaces no longer required t
steam to raise them to its own temperat
consequently, the valve was opened by
the steam, and announced the completion
of heating. The injection-cock was then
pressure of the column of water in th
leading from the tank—which was above
to force jets of cold water against th
afterwards scattered through the cylin
time the steam was deprived of its hea
its elasticity; and as it grew colder i
heat from and cooled the surrounding
partial vacuum was formed; then the
of the atmosphere being exerted on th
of the piston, with a vacuum under it
caused to descend to the bottom of t
was raised again by the steam to the top

and the process of condensing the steam by the injection of cold water was again performed. It may be added that the injection water and condensed steam descended by their own weight through an escape-valve into the hot-well below.

Such was the construction of the engine, and such was the loss of steam in alternately heating and cooling the cylinder to provide a vacuum; and Watt was led to think that he could make a much better engine.

The faults and merits of the engine were alike laid open. There was one thing in his favour, he had the privilege of beginning where his predecessors had to all intents and purposes left off. The engine had already been invented and improved upon by others; and now for the plans and improvements of the immortal Watt, whose name is known and revered throughout the civilised world. His energies were not directed to the employment of steam as a motive-power—his predecessors had done that—but they were concentrated upon its economical use; and herein lay the wisdom of the great man.

The generation of steam in a boiler was not the subject of any man's patent; but its economical employment was such, and it is so now.

To economise heat was the aim of his noble ambition—the subject of his pursuit; and there could be only one result bearing some proportion to his convictions and knowledge of the matter.

It was undeniable that when a quantity of water was heated and cast off steam, and the steam was again reduced to water in order to produce a vacuum, the process involved an expenditure of heat. The fact was patent, but it required a reasoner and demonstrator to

prove that the expenditure of heat in alternat-
ing and cooling the cylinder was three or fo
as much as would have been required to fill the
with steam to work the piston.

Straitened he was for tools, but not for de
he went straight to the point. Inserting a g
into the spout of a teakettle, he allowed the
flow through it into a glass nearly filled
water until it boiled. Seizing the glass, he f
the water had only increased a sixth part i
That such a comparatively small quantity
should, when in the form of elastic steam, ho
quantity of heat struck him with astonishmen
was something hidden! With a steady pe
and with bright hopes, he bent the whole for
mind to seize the phenomenon before him, and
the truth out of it. No wonder that a small qu
steam should absolutely surprise him in its tran
so much heat to cold water; but now he had di
hidden in the steam, *latent heat*, which had r
noticed by him before, and was not to be dete
the thermometer. Experimenting further, h
to the conclusion that a pint of water convert
steam would raise six pints of water to its ow
(212°); but that, on the other hand, a pint of
water (at 212°) would not do $\frac{1}{6}$th part as
Where was the heat, then, but hidden in the s
by which steam at 212° could raise the temperatu
a given weight of water six times more than an
weight of boiling water (212°) would do? The quan
of heat consumed in vaporisation beyond what
required to bring the water to a state of ebullition
been left out of the reckoning; and, instead of

quantity of heat in the steam being 212°, its total quantity was nearer 1,000°. His experiment was not in vain, for verily it was a brilliant discovery. This doctrine of latent heat was already known to and taught by Dr. Black, who discovered it; but Watt was not in search of latent heat—he stumbled over it; what he required he, however, found, and more, and that was, that before a vacuum could be formed under the piston all the heat, 1,000° or more, which had conferred elasticity on the steam would have to be extracted by cold water by the injection, and that the whole would be wasted.

With this valuable information now in his possession he searched further into the phenomena attending the conversion of water into steam, and he discovered a defect which disposed him to make an alteration in the engine that secured to him immortal fame.

Whilst experimenting, he observed that the injec-
ion water thrown into the cylinder to condense the
eam became hot, and therefore produced vapour
hich resisted somewhat the atmospheric pressure
on the upper side of the piston. He jacketed the
linder with wood and reduced the injection water;
; there remained steam or vapour to rob the engine
a proportionate part of the atmospheric motive-
sure. He discussed with himself the desirability
ndensing the steam without cooling the cylinder.
as, he knew, doing real work, encouraged to per-
e solely out of love for the subject; and, being
ted by the reflection of how well he had so far
ed, he pressed onwards; and, meditating on the
t issue, he conceived in his gigantic brain the
e *condenser* and the *air-pump*, which brilliant

thought solved the great proble
all who had gone before him
vacuous space in a hot cylinder
the world with the fame of t
The separate condenser was a
pump in conjunction with it
These constituted two great
previous practice. The conde
placed below the cylinder; a
expansible fluid, would, imme
from the cylinder, enter also
course fill both, establishing a
But, if the condenser was kep
a tank of cold water, steam
until the whole was condensed
Watt did. In time, the cond
of condensed steam, and theref
pump to clear the condenser wa
connected with it. Here, then,
of loss extinguished, the steam
separate vessel, and the heat of
stroke after stroke, undiminishe
maintained. Plate I. shows t
in the condenser o and air-pump

The exhaust-steam is suppo
under side of the piston, Plate I.,
exhaust or eduction pipe to the
of water is ready to condense it.
by which this kind of conden
—is distinguished. The steam,
cold water, is instantly conden
bottom of the condenser; when a
in the same manner, a vacuum

water in the condenser and the under side of the piston, and the steam which is *above* the piston therefore has no atmospheric pressure to overcome. If there were no vacuum, there would be 15 lbs. of atmospheric pressure per square inch opposed to the descent of the piston D, by which a proportionate part of the work of the steam would be lost in keeping the atmospheric air out of the cylinder. By the ordinary method of injection, condensation is not effected instantaneously but gradually, by reason that the quantity of water necessary to condense the cylinder-ful of steam must occupy some time in passing through the injection-rose. Therefore there remains at first a counter-pressure against the piston, greatest at the commencement of the stroke, and gradually diminishing as the condensation becomes more perfect.

The term vacuum, as used by enginemen with reference to the condenser, is understood, as a comparative term, to signify the absence of pressure more or less below the atmospheric datum. We know that the atmosphere will support a column of mercury 30 inches high. Now when an engineman states that he has 20 inches of vacuum, he means that the excess of the pressure of the atmosphere above the pressure in the condenser will support a column of mercury of 20 inches vertical height; or, in other words, he tells us that the pressure of the vapour in the condenser is equal to the difference between the indications of the barometer and the vacuum gauge. If the barometer stands at 30 inches = 15 lbs., and there is 20 inches vacuum = 10 lbs., then the pressure of the vapour in the condenser is 15 lbs. less 10 lbs. = 5 lbs.

Air-pump, P.—The air-pump is fitted with valves.

There are valves at the botton
there are valves above the buc
bucket-valves, the second are
the third are the delivery-val
valves were single, and therefo
pump was entirely useless. V
more valves, if one fails the pu
and the condenser kept free
and air occupying the low
below P have been drawn from
the suction-valves P during
ing into the water, the buck
the water to pass through t
side; and when the bucket a
stroke they are closed by th
When the air-pump-bucket i
the water is lifted through the
hot-well, and at the same tim
drawn from the condenser th
into the air-pump, in which a
the up-stroke, inducing the wa
and fill it. The packing for th
sists generally of tarred hemp
and properly beaten into the re
of the bucket.

Cold-Water Pump, U.—This
foot-valve and a head-valve.
well or a tank, and delivers it ab
the cold-water cistern through
water flows into the pump throu
as the bucket is making the
reaches the top of the stroke th
foot-valve is closed, and the head

pump is used to supply water for injection. The water enters the condenser, which stands in it, through the sluice o 2. Here may be found a lesson in hydrostatics. The pressure of water is upwards as well as downwards, otherwise it would not ascend the sluice-pipe.

That fluids press equally in all directions is seen in a variety of cases. If water is poured into one limb of a bent tube it will find its own level, enter the other limb, and appear at an equal height in both limbs. So that, so long as the cold-water pump supplies the cistern with water sufficiently deep to cover the condenser, the injection is in constant action and condenses the steam.

Hot-well, R.—After the water has passed from the cistern through the injection-sluice and condensed the steam, it is pumped, as already explained, into the hot-well, together with the condensed steam. The temperature of the water is generally about 100° Fahr., and is governed by the regulation of the injection water. A higher temperature would injure india-rubber valves; a lower temperature would cool down the cylinder too much, and cause a waste of fuel by re-heating it.

The water from the hot-well supplies the boilers. It is pumped by the plunger w. It is shown as being raised by the rod connecting it to the gudgeon w 2.

The delivery-valve w 4 to the boilers is closed and held down by the pressure of the steam and water at its back. As the plunger is raised water is drawn into the pump and occupies the vacant space left in the suction-pipe v 1. When the plunger is at the top of the stroke the pump and the suction-pipe are charged. In making the return-stroke, the plunger forces the water upwards through w 4, just above w 3, through which

valve it entered the pump. Let it be
the valve w 3 opens into the pump
and w 4 opens from the pump to allo
it; so that, when the plunger des
cannot get back into the hot-well.
in the direction of the stroke effects t
valve; and the great pressure of the p
forces the water out of the suction-
through the valve w 4 into the boi
the pump is fully charged at each s
conceive that the amount of water
livery-pipe through w 4 is at eac
engine represented by a volume eq
of the pump, or the product of t
plunger by the length of its stroke.

CHAPTER V.

THE CORNISH PUMPING ENGINE—DESCRIPTION AND WORKING OF IT.

THE Cornish pumping engine, Fig. 4, of the present day retains many of the leading features of the original "Watt" engine; and, in fact, some of the earliest engines manufactured by the "great man" were used in Cornwall to pump water out of the mines, and to keep them free from the influx of water which constantly pours in from the "lodes," as the metal-bearing veins are called in Cornwall. Improvements were subsequently effected by local engineers—notably by Woolf, Hornblower, Trevithick, and Grose. The modern Cornish engine has been brought to such a degree of perfection that "Taylor's" engine at the United Mines, Cornwall, is stated to have lifted 107,000,000 lbs. one foot high by the consumption of 112 lbs. of coal.

The chief peculiarity of the Cornish engine consists in the facility with which the number of strokes per minute may be regulated, varying from one stroke in ten minutes, to ten or even more strokes in one minute. This was a feature to which Watt drew particular attention in the description of his engine; and it has never been lost sight of by mining engineers. The

speed cannot be so effectually contr
steam-engine as in the type now unc
The changes of speed are effecte(

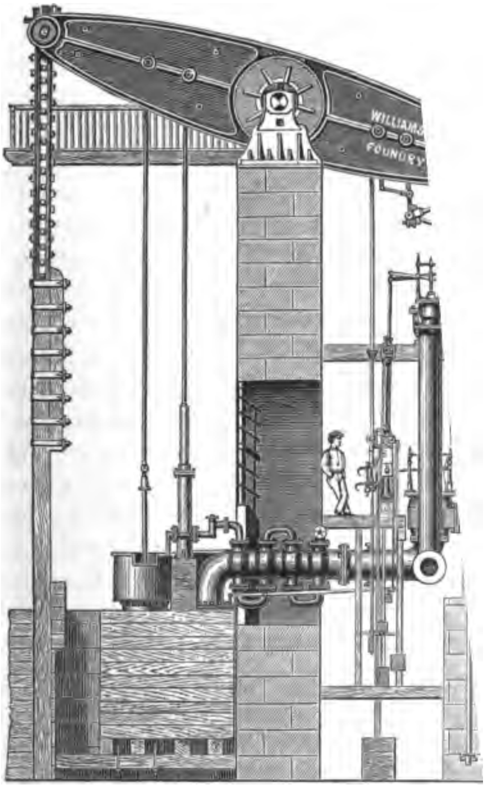


Fig. 4.—Cornish Pumping Engine.

ingenious piece of mechanism known as the
an apparatus which is fixed in the "cock-pi
floor of a Cornish pumping engine. It m

of the "box" or the "plunger" type, the former being the cheapest in first cost, and the latter the most sensitive in working.

The plunger cataract is the type most commonly employed in modern Cornish engines. It consists of a cast-iron cistern, carrying within it a trunk-plunger and case, fitted with an inlet-valve and outlet-cock, both on the under side of the plunger.

The upper end of the trunk-rod is attached to a lever which is moved by the plug-rod of the engine, either in an upward or a downward direction, according as the steam-valve or the equilibrium-valve is worked by the cataract.

It will suffice to explain the action of the "steam" cataract which controls the opening of the exhaust and the steam valves, as the action of the equilibrium or "outdoor" cataract is precisely the same as that of the steam cataract reversed. When the piston rises from the bottom to the top of the cylinder, it lifts in the course of its ascent the lever of the cataract, and with it the plunger attached to it, causing the plunger to charge its case with water by means of the inlet-valve before mentioned; when the stroke is completed, the case is of course filled with water which can only escape by means of the cock before mentioned. The outer end of the lever of the plunger is prolonged upwards towards the gearing of the engine, so as to release the steam and the exhaust catches in its upward movement. It follows that the period of release can be regulated with exactness by the adjustment of the outlet-cock, for it is evident that the more slowly the water makes its escape, the more slowly does the releasing-gear—or cataract-loop, as it is technically

termed—rise, and *vice versâ*. The power of regulating and controlling the speed in the manner described is a point which is of the greatest importance in the case of an engine which has to drain a mine or a colliery.

Starting the Engine.—In starting a Cornish engine to work for the first time, or after a long stoppage, the greatest caution should be observed with regard to the regulation of the injection-water admitted to the condenser.

As little water as possible should be admitted at first, for otherwise the engine will probably "flood" herself, or, in other words, get the condenser and the air-pump so full of water that the pump will be unable to clear itself; or, if the water be actually cleared out, it will probably be done so suddenly that, unless the driver keeps a sharp eye on his engine, and shuts the exhaust-handle quickly, the engine will come too fast "indoor" and make havoc of his spring-beam, and possibly of his "girder." This casualty is by no means of infrequent occurrence in Cornish engines, owing to the breaking of the "main" rod which goes down the shaft or pit, and is connected to the various plungers and bucket-lifts in the mine shaft. But all evil consequences arising from this case may be averted by the use of the safety cataract, by means of which, in the event of the engine making her "indoor" stroke too rapidly, the equilibrium cataract is at once released, and the steam is admitted to the bottom of the cylinder, where it acts as a cushion to break the force of the sudden downward movement of the piston, which would otherwise arise from the release of the steam-loaded piston from its load in the shaft.

Steam is usually worked in the Cornish engine with

a cut-off of about one-third ($\frac{1}{3}$), or two-fifths ($\frac{2}{5}$); although it has been worked as high as one-eleventh ($\frac{1}{11}$), when the precaution previously referred to was observed as regards a safety cataract. There is no doubt that a high pressure of steam and an early cut-off suit the Cornish engine best, as they do other engines. This was the life-long practice of Captain Samuel Grose, who did much to improve the effectiveness, economy, nd general appearance of the Cornish engine; and lthough his type of engine is not extensively known any but Cornish engineers and drivers, there are any specimens of his genius still at work.

Let it be remembered that the Cornish engine re- ires delicate handling, for this reason, that it is a 1-rotative engine, and there is no crank to measure the length of the stroke, and that, in starting the ine, on the skill and dexterity with which the ineman manages his top and bottom handles will end the life of the engine. Above all things the ne should be handled with confidence and not with lity.

the engine-driver, it may be said, remember that g as you have the handle in your hand you are aster of the engine; you can stop her, reverse ove her one inch or ten inches as easily as the of a locomotive can perform the same operation s machine; but if you lose your head, or get ned, at the gigantic inrush of the machine you t in motion, you had better give up the idea of a Cornish engine. It requires a cool head, and mind.

are a few rules for working a Cornish engine vorth remembering :—

1. Keep the cataract well supplied with wat
2. See that the exhaust and the equilibrium are sound forgings, free from flaws. Th ing of either of these may wreck an en
3. Be satisfied that cylinder and nozzle-lag well lined with sawdust, or other non ing material; and that, if the cylin case, the steam-pipe to, and the drain- it are working freely.
4. Never institute experiments with your the amusement of visitors. The eng regular amount of work to do, and th interfere with or interrupt that regu better the result. Stop, and start, a all kinds of speed, and you will cau to an indefinite extent.
5. When stopping an engine always se handles with the chain or the rods and shut the governor-valve.
6. Keep your engine clean, and keep arranged on a system. Display as in the hanging up of tools as possi monograms; do something besides t of what you are expected to do. F any branch of life implies voluntar

CHAPTER VI.

THE HORIZONTAL ENGINE—SEMI-PORTABLE ENGINE.

THE horizontal engine selected for detailed illustration in Plate II. and Fig. 5, is Robey's patent, one of a numerous class specially designed for stationary purposes, such as winding. It is also selected for the opportunity of referring to the system of firing in fire-boxes of the class here illustrated. A is the chimney, B smoke-box, C barrel of boiler, D fire-box shell, E safety-valve, F steam-pressure gauge, G water-gauge, H fire-hole door, K boiler tubes, L foundation-plate, M fly-wheel, N connecting-rod, O crank-shaft, P excentric-rod, Q piston-rod, R cross-head, S slide-bar, T cylinder-cover, U governor, V feed-pump, W clack-box, X stop-cock for pump, Y regulator-handle, 1 steam-chest, 2 valve-spindle, 3 valve-spindle guide, 4 holding-down bolts, 5 big end of connecting-rod, 6 main bearing of crank-shaft, 7 excentric-strap, 8 spark-arrester, 9 chimney-cap.

The boiler is of the locomotive type, containing flue-tubes and fire-box. The tubes are made of brass; the ends are expanded and made fast by a tube-expander, and ferrules are afterwards driven in at the fire-box end. The fire-box is, according to usual practice, made of copper; and is put together with iron rivets. It is

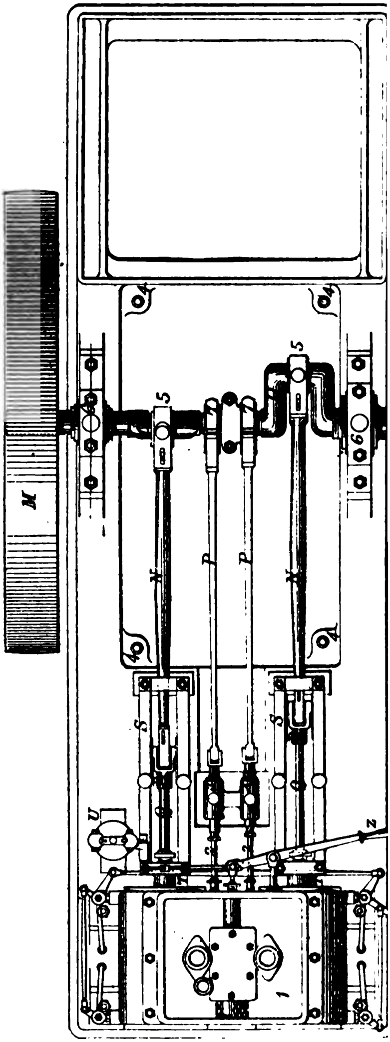


Fig. 5.—Semi-portable Engine.

fastened to the outer shell by means of a wrought-iron ring or bar, at the bottom, and another at the fire-hole.

These rings—the former of which is known as the foundation-ring, and the latter the fire-hole ring—are of the very best iron, and are carefully fitted between the fire-box and the shell, so that after these are riveted together they may be steamtight.

The sides or walls of the fire-box are further secured to the shell by copper stay-bolts. The top or crown of the box is specially strengthened, to prevent its collapsing under the pressure of the steam. The liability of the top of the box to collapse is increased by the boiler running short of water, when the copper-plate becomes much weakened.

The sides and top of the smoke-box are generally in one plate, and are secured to the boiler by means of a flanged tube-plate, which is secured to the barrel of the boiler by means of a solid angle-iron ring. The whole are of iron, and they are united with iron rivets.

The boiler-mountings include the various screw-plugs for letting out water, and for washing out; the whistle, gauge, standards, clack-boxes, valves, and safety-valves.

The cylinders are formed of cast-iron, bored out, and made perfectly cylindrical. They are bolted to the frame-plate by turned bolts passing through carefully-drilled holes, and the bolts are made to fit the holes with the utmost degree of exactness. The centre lines of the cylinders after they have been bolted together are parallel to each other. The slide-bars are parallel with the cylinders, and the crank-axle is exactly at

right angles to the line of the cy faces.

The crank-axle is of iron, and th out at right angles to each other end is on one dead-centre, the oth pressure of steam. The shaft is fit tric-sheaves, by two of which the fore-gear, and by two in reversed of these sheaves is due to the mo and piston, when one big-end is on excentric is fixed at about righ advance.

When the crank is placed on one a line is drawn through the centre circle is described on the centre of diameter to the travel of the slide-v of the centre of the circle, in a direc crank-arm, a distance is marked off of the lap and the lead; and a perpe to the centre line of the web inters above and below the centre line. T intersection show where the centre must fall, for forward and for reverse centric-rods are connected to the lin zontal motion of the link is communic action of the excentrics. At the centr horizontal motion is equal to twice th of the excentrics, and it increases to of the link. The movement of the l through the block or die in the link to which receives the maximum travel; wh excentric-rods occupies a position in a is possible with the valve-spindle,

receives the maximum throw of the excentric. The general principles of lead and lap have been described elsewhere in this book.* The action of the blast being discharged into the chimney has the effect of inducing the air to leave the smoke-box and chimney with the exhaust-steam, and thus creating a partial vacuum in the tubes from whence the air rushes to fill the smoke-box and chimney again, whilst the air in the fire-box rushes into the tubes, and the air in the ash-pit rushes into the fire. This process, if rapidly kept up, produces a constant and powerful draft of air continually passing through the fire, and the coals then receive a sufficient quantity of it in combustion to keep up the supply of steam.

Management of the Engine.—How is this engine to be managed with success? It is very natural for those who have had charge of engines to examine them when they hear something knocking, or smell something which is getting warm, or to question the state of the fire when short of steam; but, as to having any decided method of treatment, and adhering to it day after day, and year after year, because it is based upon sound rules, it is out of the question. By the non-observance of simple rules, every failure is set down to the engine.

What are those simple rules which lead up to and command success at engine-driving?

1st. From the hour an engine and boiler are set to work they are acted upon by destroying forces, and, therefore, there should be on the part of the attendant an undeviating conviction that these must be habitually followed up, detected, attacked, and effectually pre-

* See page 58.

vented from rapidly, gradually, or unifo
the machine in his charge.

These destroying forces present t
different forms, each having a characte
and the only way to overrule them is to
One is wear, and the other is tear. The s
at the same time the most efficient method
wear, is to examine the engine twice a day,
ally. Not looking askance at the machinery
detect tear and his brass filing; or into the
see if he has brought the crown nearer to th
to detect the progress of ordinary wear in
character and effects. The presence of this
the greater evil, tear, is generally not
detect.

Before the engine is allowed to make a sin
it should be examined all round, commenci
crank-shaft bearing. Brasses do best, wea
and knock least, when tightened up a little
and before they attract attention by knocking
mings do best when they are kept dry or free
when not choked with tallow, and when free
presence of glutinous matter; and, further, t
mings should be taken out of the syphon-pipe
the fire is withdrawn; and, before they are rep
is advisable to pour a little oil down the pipe
allow time for the trimming to commence w
This precaution will, in many instances, pre
journal or a slide-bar from cutting. The
should, now and then, be carefully cleaned, b
very few boxes are so made as to exclude every p
of dust and dirt, and besides many oils contain
rubber and resin in solution.

The big-ends require plug-trimmings, made of copper-wire and worsted. The wire is first doubled and then plaited in the middle several times; the bow at one end requires to be cut and the ends opened out. The worsted is then wound over and over until the plug can fit the syphon-pipe easily, not too tightly nor too slack. One end of the wire is then turned over to embrace the worsted, and the other outwards so as to fall over the top of the syphon-pipe, and to suspend the plug in it, which should not touch the journal; and at the top it should form a small reservoir for oil in the pipe by being adjusted down the pipe about three-eighths or half-inch. Such trimmings can be placed in all swinging motions.

The excentrics should be always kept in good order so as to prevent the lead of the valve from being altered. It is a good plan for a young engineman to notice their position in relation to the cranks, so that if one happened to shift by the slackening of a set-pin or a key, he could set it back into its right position.

When the engine is put into middle gear, the links can be thoroughly inspected, and great care is required to see that the split-pins in the fork-ends of the excentric-rods connecting them to the link are all well bedded.

The glands require special supervision to keep them fair with the rods, and to keep them from "blowing" steam, by packing them in time. Nothing looks so slovenly about an engine-house as leaking glands, moist steam blowing over the little-end and destroying the trimming by making it wet. When one side of the engine is done, the other should receive the same attention, and even more, for some people are apt to

conclude that because one side is righ
also.

The smoke-box and the ash-pan requ
out thoroughly every day.

Should the engineman require to tes
pistons, both little-ends must stand op
and as near the front end of the slide
when one crank will be above the sha
it. If steam is put on slightly, that
hand piston; and if the engine is r
test the right-hand piston. If the eng
gear, that will test the valves.

Further information on testing and
given in "Locomotive Engine-driving.
good thing to have made an efficient e
to have ascertained that the engine
working order. But this is only a port
required to insure success. There must

Secondly. A thorough knowledge
coals with the least quantity of smoke,
the largest quantity of heat from them.
knowledge, no man can become a first-ra
A skilful man seldom fails to seize this impo
of good management. Now, it is a fact t
of boilers having square fire-boxes, such as
ordinary portable thrashing-engines, are
the skill which is necessary to insure eco
maintain the steam regularly. When cok
the enginemen were in the habit of shovel
the fire-box without any regard or doubt a
there was a right or a wrong way to make

* "Locomotive Engine Driving." Fourth edition.
Lockwood & Co.

same indifference prevailed when coal was used. With regard to the form of a fire, what alterations were made were confined to the shape of the fire-box, and not so much to the shape of the fire. But coal-burning fire-boxes at last returned nearly to the shape of the coke-burning boxes, and attention was given to the shape of the fire; the fire was made sloping, for in the sloping boxes most of the fires were level, and the boilers would not supply sufficient steam, for the simple reason, that coal can only be burned economically when a current of air is constantly rushing through it. To effect that object, we must have regard to two things, namely, the shape of the fire, and the depth of the fire.

When the fire is hay-cock shape—highest in the centre—which may be found in thousands of instances, the necessary amount of air to carry on the process of combustion is obtained up the sides of the fire-box, and the gases there seize their portion of oxygen, and the body of the fuel is starved. The result is that when the fuel about the sides is consumed, a passage for air is made for it to enter the box and tubes without giving up sufficient oxygen to maintain steam. The fire-irons are then set to work to stop the leakage of air, and waste the fuel. There is another evil; when the fire-box draws air up the sides, the cold air comes in direct contact with the walls of the box, causing intermittent expansion and contraction, both in the box and in the tubes. The fire should be made shallow at the middle, and built up all round close against the plates. This fire will make steam when others will not; and in thousands of instances it has been found to make steam better than any other. It consumes its own smoke,

and it is the only way to obtain al
the coal; and, further, what is of e
keeps the fire-box cold-air tight. It
the locomotive service that the fir
one that consumes the least fuel and
trouble; and what is best on a railway
valuable in the boilers of the same c
stationary service.

The fire should be renewed as soon
to receive their equivalent quantities
known when perfect combustion is ta
no smoke is visible, and when the
leave the valves. By opening the fi
is slightly checked, and is prevented

The depth of the fire should be regu
upon the piston, or, in other terms, th
deeper than what admits of the air bei
by the blast or exhaust steam. Muc
in fuel depends upon the amount of
get through the fire. If the fire is
blast, the slag and refuse in the coal
fire-bars; but, provided the fire is of
and a strong current of air is kept
through it, the oxygen, by coming i
refuse, will split it up into atoms, an
tubes and smoke-box. By firing a
this may be done all the day throug
the fire-bars will be found quite
clinker. The fact of firing round t
sarily deposit the dirt, &c., in th
outside, which will assist in compell
through the centre. By doing so,
fied and spreads around, as water d

a water-can, and enters the tubes at a very hi temperature, assisting them to maintain an even p sure in the boiler.

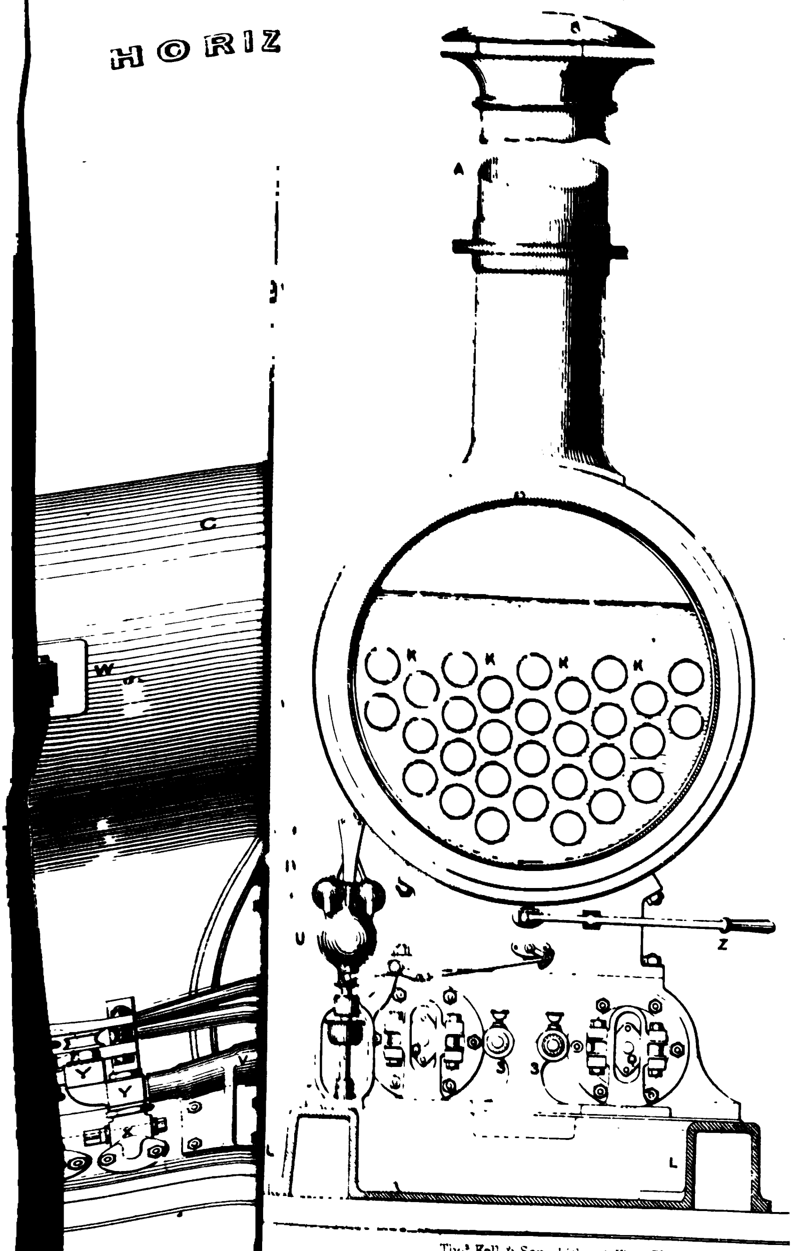
When a large quantity of green coal is charged i a fire-box, it gives off vapours and tarry matters whi adhere to the tubes, and then they become coated wi what is commonly called soot, which is unconsumed coal deposited there in minute particles. A round co six small shovelfuls of coal, one in each corner, mencing at the left front corner, with one at the mid of the tube-plate, and one under the door, should quite sufficient in all cases. The best of the coals wi fall to the centre, and a cone-like column of fire wi rise from there and strike the crown of the box, givin up much of its heat to the water before entering th tubes; and this is how it should be.

Much wasteful and unscientific firing is caused by wrongly shaped fire, by having a fire too deep, and b heavy firing. By adopting the plan herein advocated there will be less coal used, less smoke, regular supply of steam, less tube cleaning, less ashes, and a clean hearth.

Lastly. An engineman may follow out to the letter all that is here recommended; but there is one more point of importance, which should be mentioned here; and that is, the supply of water to the boiler must be regular.

It should be kept at one level in the glass, never allowed to enter the cylinders, but used freely as often as possible to make the boiler clean, and yield pure steam.

Plate 1



Thos Kell & Son Lith 40 King St Covent Garden.

CHAPTER VII.

COMPOUND ENGINES.

GREAT as was the degree to which the steam-engine had been brought by the fertile brain of James Watt, there was left ample scope for the exercise of talent, perseverance, and invention; there was still a wide field and abundant material for the exercise of ingenuity. One of the first geniuses in Watt's time, who endeavoured to reach a stage in advance of all others, was Jonathan Hornblower, a Cornish engineer of no mean repute, and a contemporary of Trevithick, Murdoch, and Woolf.

Without doubt Elihu Burritt was right when he wrote, "In human communities the collision of mind with mind contributes fortuitous scintillations of intelligence to their general enlightenment." The introduction of Watt's engines into Cornwall, together with the presence of his able assistants amongst Cornish thinking men, gave origin to scintillations of brilliant ideas. The idea which emanated from Hornblower's brain was the compound engine, in which he employed the steam, after it had done its duty in one cylinder, to work the piston in another cylinder. "I use two steam vessels," said Hornblower, "in which steam is to act, and which in other steam-engines are called

cylinders. I employ the steam, after it has acted in the first vessel, to operate a second time in the other vessel, by permitting it to expand itself, which I do by connecting the vessels together and forming proper channels and apertures whereby the steam shall occasionally go in and out of the said vessels."

Many were the hopes of the inventor regarding this engine and its superiority in economy of fuel over all its predecessors, but he said too much in his specification. After he had given an explanation why he intended using two cylinders, he went on to describe his condenser, beam, and other connections, the resemblance of which to Watt's arrangements led to a searching inquiry into the real merits of the engine. Unfortunately for Hornblower, it was decided that he had trespassed upon Watt's patents, and that the same effect was produced by Watt in one cylinder as Hornblower professed to do with two. This decision had the effect of directing the public attention in another direction. The engine proved to be all Watt's excepting a little bit.

The invention of using two cylinders, however, was never actually abandoned. Its details have been worked out to such an advantage that compound engines have much to recommend them, and therefore it is necessary that the principle should be understood by enginemen.

There were at first many objections to compound engines, arising from the complication of their construction with numerous joints. Such plans have been abandoned for simpler arrangements.

The fact of low-pressure steam being in fashion in Hornblower's time considerably annulled the advan-

tages which were sought for; modern practice has secured for the compound engine considerable advantage over that of the past by the employment of a higher pressure of steam. Many varieties of design exist, but the mechanical action of the steam is the same in all. It is begun in one cylinder and ended in the other.

The steam at a high pressure (from 60 to 80 lbs.), first enters the smaller cylinder, and follows the piston until it has moved through a certain portion of the stroke, when the valve cuts the steam off. The remainder of the stroke is performed by the expansion of the steam shut up in the cylinder, as in an ordinary single-cylinder engine. When the steam has done its work, that is to say, when it has pushed the piston to nearly the end of the cylinder, instead of being released into the air or the condenser, it is released into the second cylinder, where it acts upon the piston just as it did on the piston in the other cylinder, but at a lower pressure. Having done an equal or proportionate amount of work in the second and larger cylinder, it is thence exhausted into the condenser. Sometimes the cylinders are placed by the side of each other, and sometimes one above the other, the smaller on the top of the larger, having only one piston-rod continued through both cylinders and pistons, one connecting-rod and one crank.

Why do we use cylinders of different dimensions? If the cylinders were both of the same diameter and stroke there would be no useful result. How is that? If they were of the same capacity when the steam was released, it would act by back pressure on one piston as much as by positive pressure on the other piston

and the process would be simply a transference of steam from one cylinder to the other. Suppose that steam of 50 lbs. pressure is ready to be released from a 24-inch cylinder, and that it is allowed to enter another cylinder 24 inches diameter. The area of each of the pistons is 452·4, and 452·4 multiplied by 50 = 22,620 pounds total pressure, and the steam would oppose just as much as it would force. Now, if the same steam be released into a second cylinder having a piston area of 904·8 inches, which is twice the area of the smaller cylinder, it will exert an amount of pressure double what it does on the smaller piston. As a rule, the proportion between the areas of the two pistons is not double, but in the proportion of 1 to 4; and it is in virtue of this difference of areas that the useful work done by expanding steam in a compound engine is produced. Strictly speaking, the ratio of the areas of the two cylinders is not definitely fixed, nor is the steam in all cases exhausted direct from the smaller cylinder into the larger one, nor is the gain of work by expansion the sole consideration in using a compound engine. There is another object—to secure steady motion, and at the same time to carry out the principle of expansion with the least possible amount of injurious effect upon the machinery, by reducing the extremes of pressure in the cylinders. In expanding steam to an extreme degree in one large cylinder, a variety of evils are produced, which are obviated by the employment of two cylinders, in which the steam is expanded in succession, whilst the steam would in the single cylinder exert at the commencement of the stroke a pressure probably sufficient to do twice the work required of it, and at the end of the stroke a pressure probably only

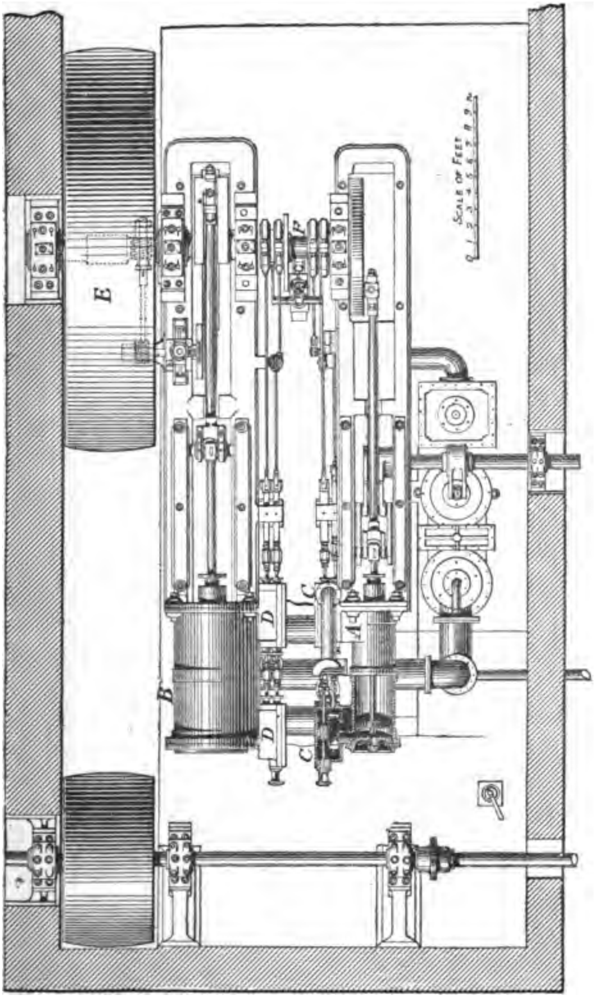


Fig. 6.—Compound Horizontal Engine.

half. Such irregular motion may be produced as might not only overstrain the engine, but the variation of the temperature of the steam in the cylinder would take place also in the temperature of the metal of the cylinder, and would react with an injurious effect sufficiently to make expansive working an expensive working. It may be added that the larger cylinder of a compound engine exhausts into the condenser.

The horizontal compound engine illustrated by Fig. 6, represents a kind of engine now extensively employed in mills for textile manufacture. Both the high-pressure cylinder A, and the low-pressure cylinder B, are fitted with double-slide chests, C, C, D, D, the object of which is chiefly to secure shortness of steam passages, readiness of access to the valves, and space between the two chests of each cylinder for adjustment of the valve-rods. The slide-valves are of the Meyer type, and are adjustable by means of right-hand and left-hand screws. The high-pressure cylinder is controlled by Allen's expansion-gear; the low-pressure cylinder is fitted with adjustable expansion gear. The exhaust from the high-pressure cylinder to the low-pressure cylinder takes place through two separate pipes; and the cranks being separated by an angle of 140°, and the low-pressure cylinder being ready to receive steam at the instant of its relief from the high-pressure cylinder, there is no necessity for a special intermediate receiver. A large drum, E, is fixed on the crank-shaft, F, from which the power is taken off by a leather belt. The cylinders are respectively 21 inches and 40 inches in diameter, and the stroke is 5 feet, making sixty revolutions per minute.

CHAPTER VIII.

CORNISH AND LANCASHIRE BOILERS.

THE system of employing steam became more generally recognised as the practical difficulties of obtaining a sufficient supply were gradually removed. There was no doubt about the economy resulting from the employment of steam, and no attempt was made to replace steam as a prime mover. The difficulties lay with the boiler. The cry was for more steam! New and larger cylinders were employed, and the demand for steam was consequently on the increase. The materials of which the earlier boilers were made exhibited unmistakable signs of weakness, and therefore cast-iron was replaced by wrought-iron for the construction of boilers. Still the mining engineers were daily making out plans for larger pumps and larger buckets with which the manufacturer of engines could not interfere; he had to find the power to work them.

There was a distinct relation between the engineer of a mining-field and the maker of steam-engines, and to this may be traced much of the improvements which attended the use of steam in its infancy. The mining engineer had no connection at all with the engine factory, and the engine-maker on no account undertook to make a drawing of pumps, lifts, &c., to drain mines.

All he engaged to do was to supply steam and machinery to help to clear a drowned-out pit.

The mining engineer was unharassed by the cares of the factory, so he could devote the whole of his energies to designing pumps. The engine-maker was unharassed by the mines, so he could give the whole of his attention to the workshop and the improvement of the steam-engine. This was imperatively necessary on account of improved mining constructions. The harmony and the distinction of interests led to a better boiler from the hands of the maker, who might just as well have shut up his shop as have closed his eyes to the fact that engineering skill was required to satisfy the call for more power. Every day's experience taught this, and many means were used to gain the desired end; but how to commence the matter was a riddle to many. A fear to deviate from a beaten track, a bigoted attachment to some favourite principle, and the want of means to conduct experiments free from theoretical reasoning, tended to keep from view the great desideratum, which was a superior boiler. But, for a long period, men looked in another direction: master minds—Watt to wit. The great mind of Watt was devoted to improving the engine and economising the steam; at the same time he was bent on keeping the pressure down. Hornblower went at the same kind of thing; but Watt, finding the world was going faster than he or others could keep pace with, looked straight into the matter, and after doing all he could to save steam by improving the engine, in advance of all his contemporaries, he invented the mill-waggon boiler, which then for a time took precedence of all others and drove many of them into oblivion. He,

however, had a deal of trouble with it, owing to the pressure of steam being equal in all directions; and *he* must have known that the form of his invention was not the best to withstand centrifugal pressure; still he held to it and passed it through various modifications of form in order to strengthen it and make it a safe and rapid generator of steam. For a time, it was as illustrious as its inventor. All this time the mining engineers were passing through a labyrinth of complexities, and Cornwall was their locality.

The Cornish engineers turned their attention to the use of high-pressure steam *versus* low-pressure steam, with the view of obtaining plenty of steam more cheaply than the "waggon" boiler could supply them. So they had to scheme an entirely different boiler, and a better one than Watt's, which, by the way, had been so far improved as to contain a longitudinal flue in the middle. Richard Trevithick, an eminent Cornish engineer, invented the boiler illustrated by Figs. 7, 8, 9, and although at the time of its introduction it was known as the "Trevithick" boiler, it is better known now, in 1880, as the Cornish boiler. It should be mentioned that, at the time this boiler was invented, there were others in use, such as the horizontal externally fired boiler, known as the egg-end boiler. But Trevithick's boiler eclipsed all others by having the grate placed within the tube, through which the hot gases passed, and then down underneath to the front where they were divided, and along the sides to the chimney. The boiler takes its name from being first employed in the service of the pumping engines in Cornwall. The furnace was thus brought for the first time into the central flue and within the boiler itself,

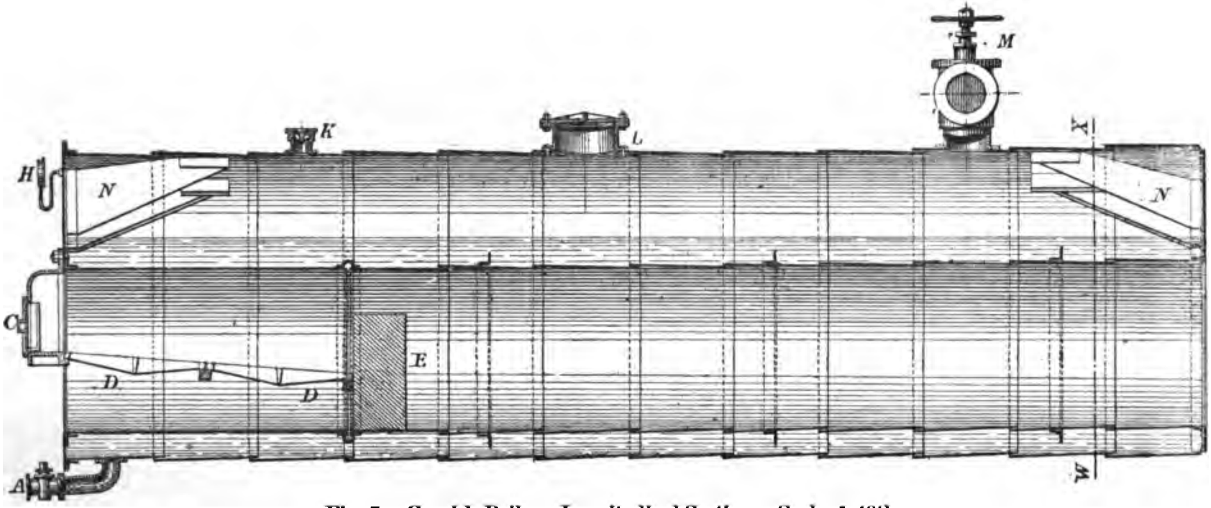


Fig. 7.—Cornish Boiler: Longitudinal Section. Scale, 1-48th.

instead of being external and u

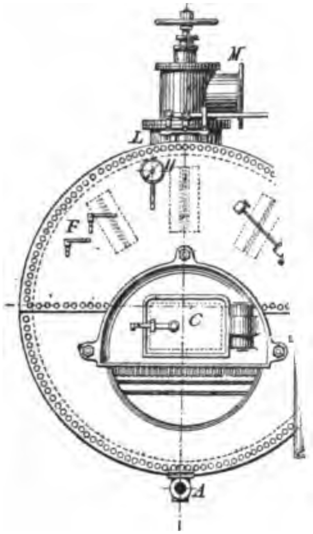


Fig. 8.—Cornish Boiler: Front View. S

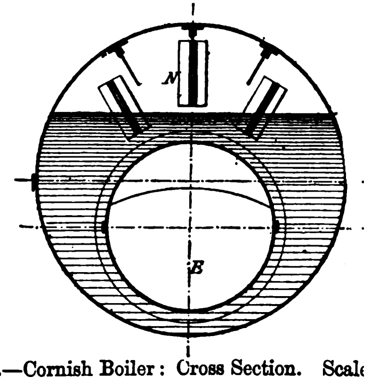


Fig. 9.—Cornish Boiler: Cross Section. Scal

predecessors. How would it act?—that w

tion; and would the heat so damage the tube as to endanger the boiler? Experienced men were quick to question how it would stand the test of working. They were not surprised to find a more perfect combustion of fuel, and the heat more effectually applied. This result was found by observing the temperature of the gases after they had traversed the tubes and were about entering the chimney. In previous boilers the furnace was surrounded with brick-work which took up the *first* heat, and this penetrating into the mass of the outer walls, radiated away into the engine-house.

In the Cornish boiler, the best of the heat is usefully applied on the heating surface, and the remainder only is extracted by the masonry, so that the process of absorption was reversed. The results were highly favourable to economical working, and it very soon became popular. Many contended that, to obtain the greatest effect, the heat should be applied to the bottom of the boiler; others contended that a convex heating surface was superior to a concave one. But experience proved, when the heating medium was inside a boiler, and applied to a concave crown, it was a far superior steam generator to any that had gone before it. A concave heating surface is superior to either a flat or a convex one.

Bury's round locomotive fire-boxes would make any amount of steam, and herein their strength lay. The fire-boxes of the present day, with vertical sides and concave tops, make steam better than the square boxes.

The Cornish boiler was not only a new form of boiler, but it was made to withstand high-pressures

which frightened most people; but Trevithick intended it for high-pressure, and he was the man who introduced it for the purpose of affording scope for the carrying out of the principle of expansion by cutting off the steam earlier than others did, and, by doing so, economising fuel. When high-pressure steam is cut off very early, the inequality of the steam's action on the piston requires to be practically neutralised. This is done by the fly-wheel.

The Lancashire boiler, Figs. 10, 11, 12, is a native of Lancashire, and was the outcome of a desire to insure safety. The internal flue of large Cornish boilers occasionally exhibited signs of weakness. It was subjected to an enormous degree of expansion which bulged the ends out, and when it was stiffened and stayed, so that it would not yield, the internal tube became hog-backed within the boiler; then, by sudden contraction, when the door was opened for firing, it was straightened. Consequently the boiler became unsafe. To maintain the size of boiler necessary for the supply of steam, and to retain the principle of an internal grate, the boiler was converted in Lancashire into a double Cornish. There are reasons for inducing us to admire this boiler, from the point of view of the stoke-hole. When the furnace is six feet or more in length, it requires more than ordinary human muscular action to send the coals to the extreme end of the grate; and where there is not the strength to do so, the bars soon become bare; then, to keep the steam up, the rake is put into the fire to knock it about, and to blaze the coals away. Besides, in a big boiler with a big grate, one will generally find by the side of it, to *keep it warm*, a *big* draft. In

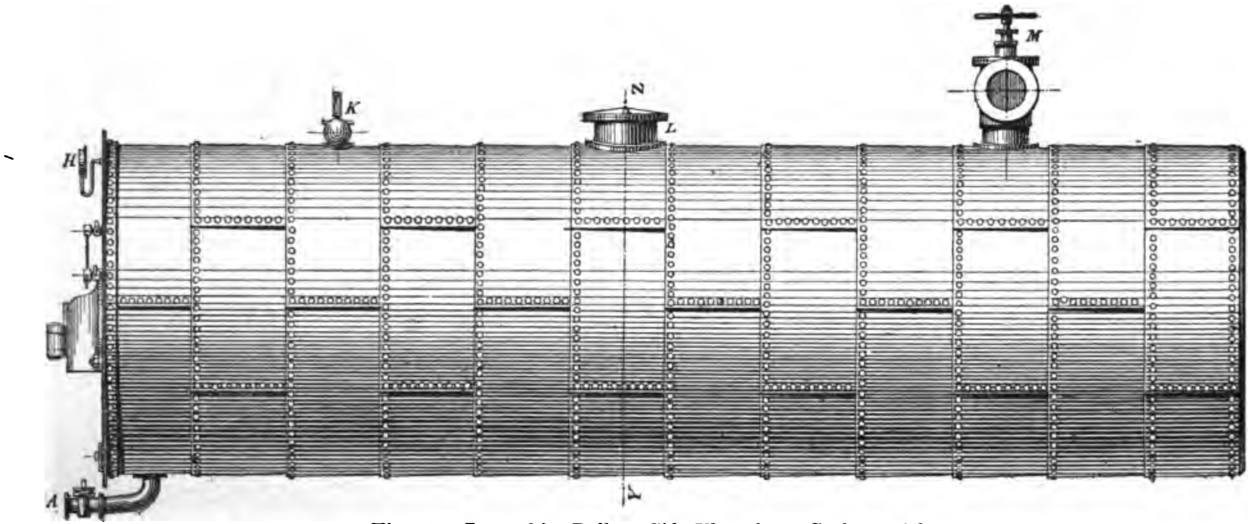


Fig. 10.—Lancashire Boiler: Side Elevation. Scale, 1-48th.

some instances, the boiler is overpowere

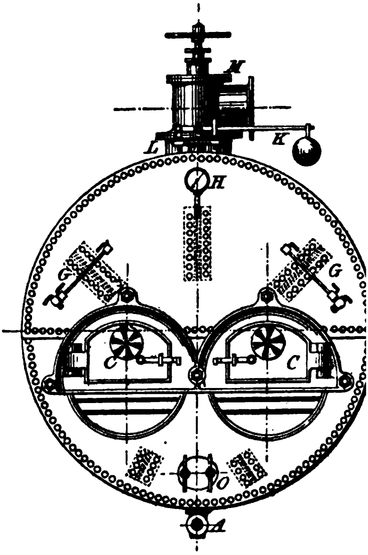


Fig. 11.—Lancashire Boiler: Front Elevation.

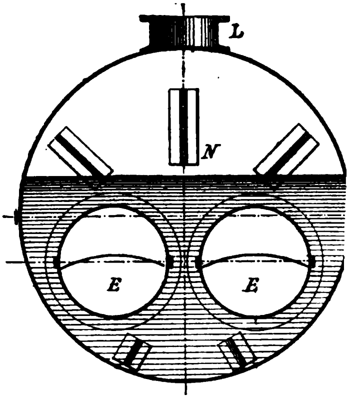
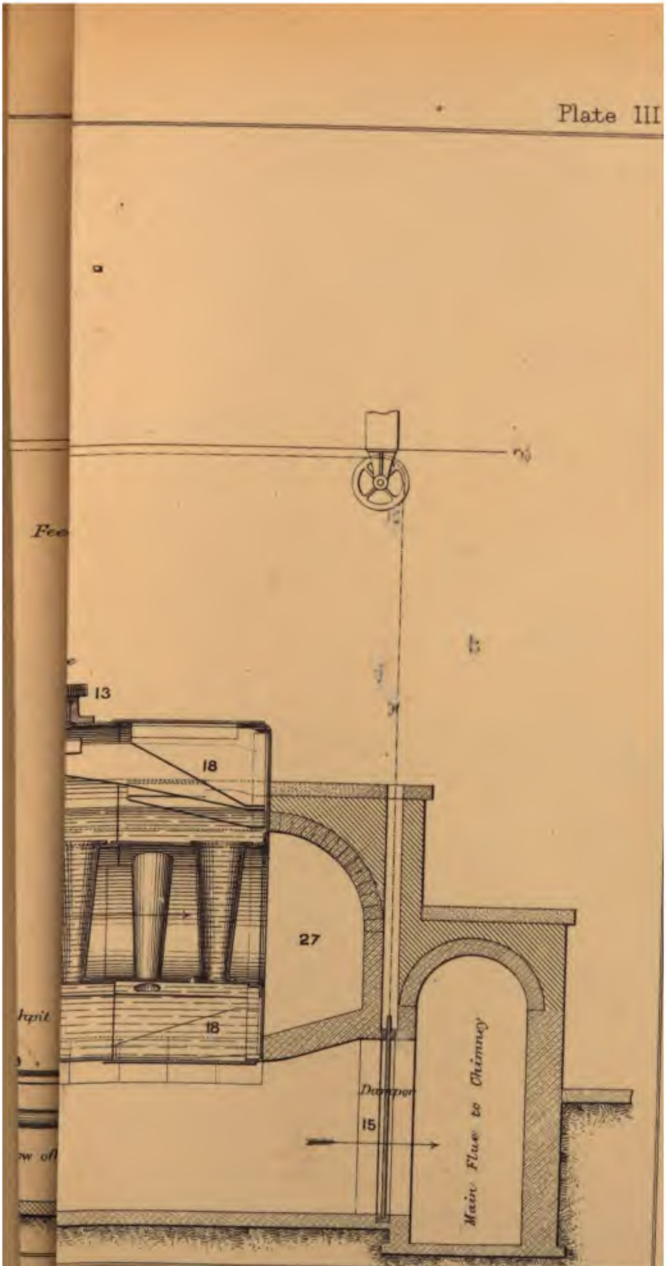


Fig. 12.—Lancashire Boiler: Cross Section.

rule it is done because the thing looks in keeping. Now with a large grate of 6 feet long by 3 feet 4 inches wide, the fire is too low below the furnace top for the hot gases to come in contact with the plate, and as soon as the attendant closes the fire-door, the strong draught pulls the gases out of the furnace without their being properly ignited, or being by a slower draft allowed to touch the plate above. If, instead of this grate, we had two grates 4 feet long by 2 feet 7 inches wide, the attendant would with certainty cover the whole grate by means of the shovel, which would keep out the rake and save coals. Besides the fuel would be nearer to the crown of the furnace, and the water and the draft would be split.

The illustrations show the difference in the two constructions, and they will enable enginemen to learn the reason of one being called a Cornish, and the other a Lancashire boiler. As there are scarcely two boiler-makers who put their boilers together alike, it is unnecessary, while noticing the boilers, to advocate any particular design or class, for the simple object of this work is to explain such things as are useful, and are calculated to raise the mind of those in charge of engines and boilers, and to induce them to study the questions hinted at here, in the works of others.

Plate III



Thos Kell & Son, Lith. 40 King St. Covent Garden.

CHAPTER IX.

THE GALLOWAY BOIL

THE general arrangement and co latest improved "Galloway" boiler is

Longitudinal section . . .
Plan . . . . . .
Front view (Section on line A B) . .
" " (" " C D) .

In many respects and in general appea of the Lancashire type, which as hgiv results in England.

1. Main steam-pipe.
2. Feed-water-pipe.
3. Safety-valve.
4. Steam-gauge.
5. Water-gauge.
6. Fusible-plug.
7. Furnace.
8. Mud-hole.
9. Ash-pit plates.
10. Blow-off-cock.
11. Flue-door.
12. Steam junction-valve.
13. Man-hole.
14. Feed-v
15. Dampe
16. Dampe
17. "Gall tube
18. Gusset
19. Pocket
20. Side fl
21. End of
22. Botton
23. Fire-li
24. Water
25. Steam

The Galloway boiler has now been twenty-five years, and is used in United Kingdom, supplying steam to powerful engines, and giving great sati Philadelphia Exhibition of 1876, thi of boilers were tested, including the

with the view of ascertaining their respective merits as economical and satisfactory steam generators. Each boiler was tested separately for eight hours, observations being taken every twenty minutes, under ordinary working conditions, and a pressure of 70 lbs. to the square inch was regularly maintained throughout each trial. The test was conducted as follows:—Steam having been raised to 70 lbs., the height of water in the boiler was noted, and the fires were drawn. The fires were then relighted with fuel, which was weighed and charged against the boiler; all the additional coal supplied for the trial was also weighed as it was served out to the fireman, and allowance was made for the coal which remained unconsumed in the furnaces at the termination of the trial. Observations were made to test the state of dryness of the steam by condensing a certain weight of steam in a given quantity of water. The dampness of the steam or the moisture it contained was calculated from the increase of weight of the water and the rise of its temperature.

The feed-water supplied to the boiler was measured and also weighed, the force-pump for supplying it being fed by steam from the boiler on trial. The results arrived at are embodied in the table below, from which it will be seen that Galloway's boiler (Patent 1875) attained the most economical result, evaporating 11·72 lbs. of water at 212° Fahrenheit per pound of combustible. In addition to achieving the most efficient evaporation, the boiler yielded the driest steam. Anthracite coal was the fuel consumed in testing all the boilers, excepting the Galloway boiler, which, being more suitable for bituminous coal, was tested with that description of fuel:—

Description of Boiler.	Heating Surface in Square Feet.	Horse-power at 1 Cub. Ft. Water evaporated per Hour.	Lbs. of Water evaporated.			Percentage of Water in Steam.	Lbs. Coal burnt.		Temperature of Gases leaving Boiler.	Cub. Ft. of Water Space per Horse-power.	Cub. Ft. of Steam Space per Horse-power.
			Total.	Per Hour.	At 212° per lb. combustible.		Per Hour.	Per Sq. Foot of Grate per Hour.			
Galloway . .	973	41·64	20,824	2,603	11·72	·57	283	7·269	324	14·10	4·04
Root . . .	1,590	54·29	27,146	3,393	11·565	not taken	381	9·09	393	2·29	·89
Firmenich .	1,078	26·46	13,233	1,654	11·53	not taken	185	11·79	415	4·08	2·63
Lowe . . .	774	21·45	10,729	1,341	11·489	not taken	153	6·805	332	9·02	2·63
Babcock . .	1,680	62·70	31,358	3,919	11·489	3·24	444	9·77	295	3·74	2·20
Andrews . .	540	18·94	9,469	1,183	10·513	not taken	148	not taken	419	4·14	1·29
Wiegand . .	1,355	68·08	34,042	4,255	10·461	not taken	517	12·32	523	2·66	·64
Anderson . .	1,135	44·44	22,230	2,778	10·255	not taken	350	9·747	417	1·43	1·28
Kelly . . .	662	37·41	18,710	2,338	10·099	5·97	291	10·82	not taken	1·91	·68
Harrison . .	900	36·57	18,285	2,285	10·022	1·11	284	12·36	517	1·93	·80
Pierce . . .	200	23·74	11,876	1,485	9·818	5·53	199	7·99	373	·65	1·64
Exeter . . .	1,525	32·65	16,334	2,041	9·765	4·63	280	9·35	429	2·66	1·43
Rogers and Black	399	21·13	10,564	1,320	9·31	2·68	181	8·05	571	1·71	1·17

Description of the "Galloway" Boiler.—The shell is made of nine rings of plates, about three feet in width; each ring being made up by three plates in the circumference. The transverse riveting of the circular seams is single—that is to say, there is one row of rivets. The longitudinal riveting, for the longitudinal seams, is double riveting.

It has been found by a series of carefully conducted experiments that the double-riveted straight seam is considerably stronger than the zigzag plan.

The plating of the shell is what is termed parallel—that is, the plates are bent truly cylindrical, so that the successive rings of plates are alternately lapped inside and outside. Thus—

Fig. 13.—Plating of Boilers.

This system is an improvement on the old style of conical plating, where each ring is lapped outside at one edge and inside at the other edge. On this system all the plates are required to be cut tapering; on the other system the plates are rectangular.

The front end-plate is securely attached to the shell by an angle-iron, and is turned on its outer edge. The holes in the furnace-plates are carefully bored out in the lathe. The back end-plate is connected to the shell by flanging, so as to allow sufficient play for the expansion and contraction of the flue. At the back end the flue is connected to the shell by means of an angle-iron ring.

The furnaces are each in three rings, welded longi-

tudinally and flanged transversely
ring between the flanges; thus all
of the fire, and there is ample st
the pressure of the steam. The tu
the front end-plate by angle-iron
bridge they are connected to the
pockets and patent cone tubes. T
at the bottom instead of being co
formed. By this improvement r
provided underneath for the pa
inspect, clean, or repair the boiler.
flue converge towards one centr
curves of the top and bottom of
They are all alike, and are interch
tubes are flanged square to their c
is put upon them in their mai
obliquely formed, as before.
boilers are made by machinery
accuracy is secured than whe
by hand. These tubes are 5½ i
the smaller end, and 10½ inche
larger end, so that the smaller en
drawn through the hole cut in th
larger end of the flue if at any
required to remove a tube. Pra
necessary to remove or renew a tul
as long as the other parts of the boi

The taper form of the tube allo
steam to rise as they are formed, in
of the surface of the plate. This i
if the water is kept off the plate by
generated there, the tube is liable to
burned out.

Pockets are placed in the flue, which deflect the flame amongst the tubes when it would otherwise seek a direct passage.

At the back end the flue is reduced, where it is connected to the shell, by contracting pockets, in order to allow of the necessary expansion and contraction which the flue of the boiler undergoes when at work.

The ends of the boiler are stayed to the shell by a number of gusset-plates, several of which are extended to the second plate of the shell, in order to give additional holding strength. They are attached by double angle-irons, and they are not brought nearer than eight inches to the crown of the furnace or of the flue. By such a provision scope is allowed for the expansion and contraction. If the connection were too near and too rigid the end-plate would be overstrained, and grooving would be the result.

The boiler is fitted with a pair of doors having a brass grid, by which the admission of air is regulated according to the state of the fire. Inside the furnace, at the entrance, there is a dead-plate, next to which are the fire-bars of cast-iron, in three lengths, resting upon cast-iron bearers. The fire-bars extend to the bridge, which is made of fire-bricks of a height sufficient to deflect the flame towards the crown of the flue, without checking the draught. On the front of the boiler there are two water-gauge glasses, having a pointer showing the best level at which the water should be maintained, leaving ample steam-room in the boiler. The gauge-glasses are connected at the bottom by a drip-pipe, which carries the waste water to the drain—not into the ash-pit. A steam-gauge is fixed

on the front-plate, as near to the top of the boiler c possible, in order to keep it cool and in good shell-p The safety-valve is placed on the first shell-p the boiler: consisting of a mitre-valve with a le a weight, which can be adjusted to any pressu function of the safety-valve is to give notice pressure of the steam rises too high, and to r boiler of surplus steam. A man-hole is p the top of the boiler, about seventeen inches i —sufficiently large to allow a man to get boiler.

There is a mud-hole B at the front. the boiler, near the front, there is a blow- which is connected by a curved pipe to riveted on the boiler. This cock is opened during the day to let off the mud which col bottom of the boiler. It is also opened boiler is required to be blown-off altogether.

A steam-nozzle or stop-valve, 12, is also It is a valve which is set down or closed by of a hand-wheel and screw. Underneath the inside the boiler, there is an anti-priming pipe, w is formed with a number of perforations, throu which all the steam passes from the boiler for th supply of the engine. The water is separated in the passage, and is sent back into the boiler; thus a supply of dry steam is reserved.

The main feed-water-pipe is connected to a feed- valve by a curved pipe, as shown. This valve acts also as a back-pressure valve; that is to say, although it allows water to pass into the boiler, it does not allow the water to return.

Inside the boiler there is a long perforated pipe, by

which the water is effectually distributed instead of being allowed to enter the boiler at one spot, which might be injurious.

The boiler is also furnished with a damper and tackle, ashpit-frame, and foot-plates, placed just in front of the boiler. Flue-doors are placed in front to give access to the flues of the boiler.

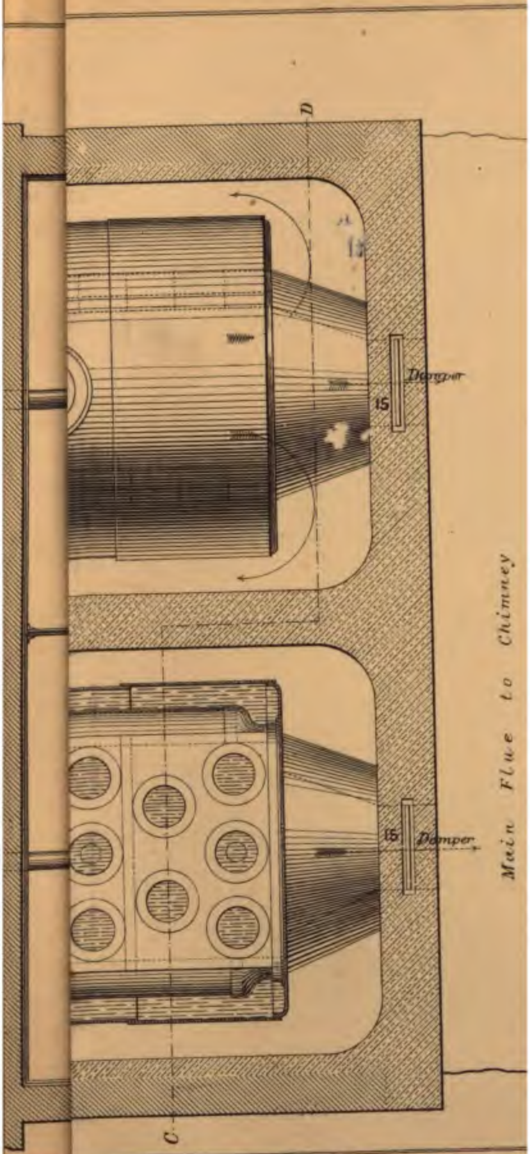
After the current of flame and hot products has passed through the boiler, it is split and passes round the sides; then it dips and passes underneath the boiler, and thence past the damper to the main flue.

The method of conducting the gases along the sides first, and afterwards along the bottom, is found to act much better with the Galloway boiler than the reverse order of passage—under the bottom first.

The boiler is set upon lumps, which are better and more easily fixed than fire-brick.

The setting of boilers has been much improved. There was a time when the flame in the side flues was allowed to impinge upon the plates of the boiler above the water-line. The plate, in consequence, was liable to become overheated to a dangerous degree, and weakened by the sudden access of occasional draughts of cold air, by which their temperature was suddenly and unequally reduced. All the heating surface in the flue—that is, the surface of the boiler which is exposed to the heated gases—should be below the water-line, with a margin of safety. The plates at the side, when they are exposed to frequent changes of temperature, must inevitably become a source of danger.

Another barbarous practice is to set a boiler upon a bed of wet brickwork and mortar, on a wet foundation, exposing the plates to corrosion as soon as the boiler is



Thos Kell & Son, Lith. 40, King St Co

set to work. Corrosion under such circumst
ceases in the work of destruction until it h
tated the boiler being lifted off the brick
patched.

Formerly, boilers were supported on the c
mid-feather of raw brickwork, so that wate
leaking rivet or joint would naturally run
boiler side and assist the corrosive agents
destructive work in the neighbourhood of
which rested on the middle support. Th
alarmingly intensified by the extent of the
in width and in length, touching a large a
to the work of destruction. This dec
worked in the dark. How was it possible
examine what was going on under a b
centre of an 18-inch brick wall extending
of from 20 to 25 feet? Is it surprising
have suddenly *left off working*, and ascende
down a factory with them in their descent.

Boiler after boiler explodes, whilst the cau
plosion can be clearly traced. Little by litt
tions and improvements are made, which l
reduction of the number and extent of accid
explosion. Much of the amelioration is due
invaluable influence and the good manageme
boiler insurance companies. But all that can be
is not done; the men in charge of boilers should
certificates of service and competency.

CHAPTER X.

DETAILS OF THE GALLOWAY BOILER.

Safety-valve, 3 (Plates III., IV., V.).—The invention of the safety-valve was one of the most important of any connected with the steam-engine. The invention is generally ascribed to Papin, a French physician and engineer; but weighted valves or plug openings were made before his time. Some of the ancient steam-deities were so fitted. But Papin did for the safety-valve what Watt did for the engine: he extended and improved it, with respect to the mode of employing it, by means of levers and movable weights; and thus he prevented the valve from being blown off its seat. He made one valve to do the work, or answer the purpose, of many, by regulating the pressure upon the one valve by weights. Practically, he was the inventor of the steel-yard safety-valve as an improvement upon the dead-weight or direct-weight valve; and so long as safety-valves are used the world will be his debtor. Many wonderful tales have been told about safety-valves sticking upon their seats until the boilers they were supposed to keep safe have either blown up or collapsed. It is possible for a valve to stick, it is possible that it would cause an explosion;

but the liability to accident can be
prevented by proper design, fitting, a
Safety-valves are either flat-faced
contact of the former may be termed
the latter is a mitre-seat. Both are
indirectly by levers or directly by
helical-springs. Sometimes the dea
tached to the end of the valve-spindle,
course inside the boiler; but dead-weig
way of occasionally becoming detac
away goes the valve through the roof
house, followed by a discharge of ste
which prevents any one driving a wo
the hole until the boiler becomes nearly
flat valves and mitre-seated valves are e
their seats by inside wings or by
Central stalks or spindles are apt to g
accident of falling from a bench, or from
to a stone floor. The injury is not dete
valve is returned to its place and the s
blow "through" much below the boiler
cause may remain a mystery until all
blown off from the boiler and the val
Then even it may be thought to be a
when it is put into a lathe, between th
discovered to be "drunk," that is, not perf
It may be only out of the straight by th
a bee's wing, but steam is a gas, and tl
valve must be closed all round by the
valve; otherwise steam will escape wl
the slightest defect. Central spindles hav
defect, and that is that they are liable t
guide-hole inside the pipe below the sea

working up between the spindle and the sides of the hole. In many instances, when boilers have been out of use for a time, the valves have been found as fast as a rock, by corrosion. The conical or mitred valve with three stalks or wings is universally acknowledged to be the better valve. It is seldom found to stick unless it is imperfectly fitted, which may arise from its being made too good a fit, and not being allowed freedom of action under a change of temperature, or of other working conditions. When it is fitted into a cast-iron seat, itself being brass, the relative contraction and expansion are not the same, and the valve is then apt to bind and to deceive; and therefore to become a thousand times worse than no valve. The valve, as well as its seat, should be of hard gun-metal. The angle for the cone should be 45°, and mitred not more than an $\frac{1}{8}$-inch in width for contact. Many valves do better and wear longer with a $\frac{1}{16}$-inch mitre. The disadvantage of having too broad a mitre face on the valve is, that when the valve is opened by the steam this penetrates or insinuates itself between the conical faces of the valve and its seat, and acts upon a considerably larger area of surface than when the valve is down on its seat. Then, as a consequence, the valve, once opened, will not drop again into its seat ntil the pressure is diminished below that which ufficed to lift the valve, which is supposed to be the itial blowing-off pressure. Besides, with a wide face, e valve does not cut the steam off so clean and so mptly when the pressure underneath subsides, as a row-faced valve does.

he lever of a safety-valve should not be unneces- y long—not longer than is required for the highest

pressure at which the boiler can b
pressure cannot be increased acci
Whatever length the lever may have
he chooses to do so, can place addition
lever, and so lead to such an increase
as to burst the boiler. It will be notice
safety-valve on the boiler illustrated by
lever is bent downwards. When a valv
held down by a straight lever, there is
when the lever is pressed down at the
spring or weight, to jam the valve by
thrust, caused by the centre of contact bein
point where the thrust takes place, which
avoided by bending the lever.

Safety-valves should be allowed to blo
every day, when their condition and accur
tested with a "Bourdon" gauge. They sh
be fixed out of sight—inside a pipe, for insta
the object of carrying the steam outside th
the boiler cannot be worked so as to avoid b
the valves should go outside the roof as w
chain attached, so that the engineman ca
them. Of course, there they are more expo
corroding influence of the weather outside, an
place is on the boiler, it is better that they s
fixed there—removed as far as may be from
ing for steam to the cylinder.

It is a very useless act of enginemanship
valve off its seat with a boiler full of steam, as
a great and instantaneous rising of water and
the form of a cone, towards the valve; and wh
valve is suddenly closed the water reacts upo
valve as a fulcrum and drives back with great fo

the bottom of the boiler, the effect of which has been sufficient to cause an explosion in a weak boiler.

It is necessary that every engineman should be able to calculate the necessary weight to apply at the end of the lever to balance a certain pressure on the valve, so that he may have a kind of command over what is in the boiler. Such knowledge gives a man a higher estimate of his berth; and gives him an air of confidence such as knowledge only confers. After a boiler is reduced in strength through wear and tear, it is a common occurrence to reduce the pressure by shifting the weight, which is often done without any calculation whatever. But it is far more business-like to make a proper calculation. Examples of such calculations will be found at the end of this work; but it may be opportune here to mention that the principle of the safety-valve-lever is very simple, thus (Fig. 14):—

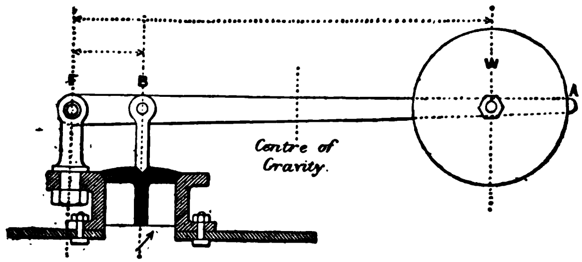


Fig. 14.—Safety-valve.

W is the power applied at different distances along the lever between A and B—the valve. The steam endeavours to leave the boiler by virtue of its elasticity, and constitutes the resistance at B. The greater the distance between B and F—that is, between the power and

the fulcrum—the greater is the le… valve at B. If W and F are 17½ i… and F are 3½ inches apart,

$17\frac{1}{2}$ in. $\div$ $3\frac{1}{2}$ = 5, the leve…

then a weight hung on the lever a… influence five times that of an e… because *it is five times* as far betw… from B *to* F.

The proportion which the power… or resistance *is as* the distance of… *fulcrum is to the distance of the* p… *point. In a word, the power and* … ance are *inversely* as their dista… crum.

Fusible-plug, 6.—Fusible-plugs ar… nace-crown *to prevent, or rather* … insufficiency *of water in the* boi… instances *their value is annulled* b… short in *the inside of the* boiler. I… their length *allows them to project in* … very short *distance, they give alarm* … actual *danger, instead of being a* … actual sense *of the word. A plug sh*… of danger *long before the fire can in*… this can *only be done by making the* … length, and *there is no reason why t*… stand up *in the water an inch or m*… line. *When plugs are too short the* … covered *with stony scale, and alth*… alloy may *be melted out the scale* … water from *entering the fire and ra*… danger. *By giving them a reason*…

have more chance of answering the purpose for which they are inserted in the plate. Although it is desirable not to have many holes in any boiler, in order to secure unimpaired the normal strength of the plate, yet it is a very desirable precaution to have more than one fusible-plug in every boiler.

Plugs should be fixed fore and aft the furnace-crown. In some instances, several small plugs are clustered together, fitted into a seating which is attached by rivets to the centre of the crown, but the accumulation of scale over this seating may render the whole of them practically useless. When a furnace is fitted with duplicate plugs, the investigation into the cause of the melting of one is much facilitated. The other remaining intact is a proof that the furnace-plates have not been overheated.

Many instances could be cited where much suspicion would have been averted and full confidence retained between an employer and an engineman if duplicate plugs had been used. We have duplicate gauge-glasses, and why not have the same laudable principle of security carried into the furnace?

A plug may be blown out through being worn out, and every engineman is aware that when the alloy gives way it causes much annoyance. This circumstance has caused very much inconvenience through the attendant not knowing how to act. But to prevent any unnecessary delay, the discharge of steam and water should be temporarily prevented by driving a wooden plug into the hole: this is attained by providing an iron rod of sufficient length capable of conveying the plug to the hole. It is a ridiculous idea to stop a mill or a locomotive simply because a hole half-inch or less in diameter

cannot be plugged for an hour or
can be properly restored.

Care should be taken to renew a le
possible after it commences to leak
weeks and not give way; but the e
to the wasting away of the plate ab
necessitates a patch, the plate havi
ously thin. Now a thin plate above
most dangerous of all places abou
weakest part of a boiler should be th
plain reason. When a plug gives
should be closed and the fire dampe
so as to prevent an increase of steam
by an induced current of air follow
steam made by the water being ins
as it comes in contact with a larg
These plugs often become dangerous
they reach the temperature at which
to give way, and then they blow out.
is not always evidence of the furnace l
heated. If they blow out when the
steam, just close upon the normal pre
the steam will suddenly rise and lift
alarm of the engineman, whose attenti
fixed upon the coincidence of the circ
blowing out, and steam allowed to esca
and the safety-valve allowing escaping
engine-house. He naturally thinks
burst, and flies to the pump. The sud
occurs in the boiler through the pr
being suddenly diminished; and the
plug-hole being put in a state of m
escapes out of the water into the steam-

Floats.—This class of gauges is fast going out of use. It consists of counter-balanced weights; the weight in the boiler is frequently a stone which floats on the top of the water, by the difference between its specific gravity and that of the water being counter-balanced by a weight outside the boiler. The two are connected by a wire suspended over a pulley. The wire works through a stuffing-box in the shell of the boiler, and the rise and fall of the water is shown outside by the position of the weight hanging by the side of the pulley.

It has many defects and requires well looking after. Its cardinal fault is that it is too sluggish, and requires more sensibility to record the position of the water with satisfaction than its principle will admit of. The varying positions of the water are not brought home to the attendant with such force by the float as by the gauge-glass. Then, again, the wire, when of iron, soon becomes oxidated and works in the stuffing-box with an excessive degree of friction which is highly dangerous. Again, this wire, if made of copper, is liable to stick by being packed too tight; and there is, further, the possibility of the wire being damaged and bent. Should it break, the business is all over until the steam s blown off, the manhole-joint broken, and the float is shed up by a "nipper" lad. When the float is to be paired, there is the joint of the manhole to be -made; and by the time everything is ready to start ain, the accident has cost a sovereign. Nothing of kind takes place with gauge-glasses, which make eat and certain register, without any inconvenience tever.

Then floats are in a leaky condition at the stuffing-

box—and it is scarcely possible to prevent and t for any length of time—the water down steam fall on the boiler, and trickle down unde into some quiet cranny, so deep down as to be out of sight—that means, in many c mind until the boiler gives out by corrosion. glass indeed!" said an engineman; "I pr Look what a box you would be in if a bosted in the night," continued he, with wink, which implied that that was a cle gauge-cocks can be closed at night, and closed. Is any reliance to be placed in self regulators? None whatever; they soon tive and worse than useless. They a worked in connection with the float, by m and valves; but they soon get out of ord leak, especially if the water is at all hard.

But the worst feature in the float is that boiler attendant an idea of security—whe there is no security at all. When a man k the water-level in the boiler regulates itself easy about it, and he does not give the prope of attention to the varying height. There is like keeping an engineman in a state of intel activity. He is all the better for it, and he kno and is ready to acknowledge it.

There is a report about that the enginemen of present day would be completely lost if they had to the intellectual part of what was performed by years ago, both in stationary-engine working and locomotive working. The machinery is so near perfect that the work that is required to be done is

same over and over again, until the man in attendance becomes a machine himself. But if a break-down happens, be it the bucket of an air-pump, or a foot-valve gone, he is not sure exactly what he is to do. Many men cannot act on an emergency—some men can.

The Steam-Pressure Gauge (*Bourdon's Gauge*), 4, is constructed on the principle that a hollow elliptical metal ring will uncoil itself by its elasticity when the pressure which is applied to it by the steam admitted internally is withdrawn. The construction is this: A hollow brass hoop of an oval cross section (thus ⬭), into which the steam passes, is secured at one end to a brass plate, which is fitted over the steam entrance to the gauge, the joint being made steam-tight. The other end, which is closed, is attached by means of a small arm to a toothed sector, which is geared into a small pinion upon the spindle to which the index-pointer is attached. The steam entering the hoop causes the end which is attached to the sector to move outwards from the centre; this causes a corresponding movement in the pointer, transmitted by means of the arm, sector, and pinion; the movement continues as the pressure of the steam increases.

The hoop, arm, sector, pinion, and frame, to which they are hung, are all of brass. The use of the inverted siphon-pipe is to collect a small quantity of water, so that it may act as a cushion between the steam and the working parts of the gauge; also to prevent injury, as the steam permeating the gauge would in time spoil its action, loosen the enamel from the dial, and also dim the glass so that it would become unreadable and unsightly. The cock which is placed at the lowest part of the inverted siphon-pipe is designed to draw

off any water which may have collected ... water was not drawn off it would rise into ... and the steam pressure would in consequen... rectly indicated. The steam-pressure gaug... indicate the total pressure of the steam, ... pressure above the atmosphere. The steam ... measured from the pressure of the atmosph... 0, or zero, on the gauge. When the index o... shows a pressure of 50 lbs. per square inch ... 15 lbs. atmospheric pressure to be added t... making 65 lbs., to give the total pressure ... All pressure gauges should be provided ... stop-cocks to shut off the steam from the ... the gauge can be taken down and repair... is put in its place, the bend in the pi... filled with water, which transmits the pr... steam to the spring at a low temperature; ... munication with the boiler should be open... so that the sudden impulse of the steam ma... the spring in the dial.

Every boiler should be fitted with an i... steam-gauge, fixed so that it can be readil... any one entering the boiler-house.

In frosty weather, the water in the tube is ... be frozen, and the tubes require to be lapped wi... yarn or some other non-conducting substance ... owners of steam-boilers should provide a check ... to detect any recklessness or oversight on the ... the engineman, by erecting an alarm pressure ... by means of which an accurate and faithful re... the boiler pressure may be rendered in the office ... It is fitted with an alarm-bell and can be set ... pressure, and so soon as this pressure is reach...

bell will ring. A large saving of fuel can be effected by adjusting the ringing pressure below the blowing-off points, and indirectly save unnecessary straining of the boiler either by over-pressure or by intermittent expansion and contraction, as it registers the pressure at any moment. It is especially useful where the engine is required to run as uniformly as possible. It incites those in charge of engines to the utmost care and vigilance, by furnishing them with a correct account of the result of their efforts to work the boiler as nearly to one temperature as possible.

Low-water Alarms.—Pinel's water-level indicators, acting by magnetic force, as constructed by Messrs. Lethuillier and Pinel, have given satisfaction; but they are indirect and delicate in action.

Duryea's electro-magnetic low-water alarm, on the contrary, is positive in action. It provides for the sounding, with certainty, of a call or alarm at any distance from a steam-boiler, when the water falls below a given level. The circuit-closing apparatus is enclosed in a tube fixed on the front of the boiler; and it stands, when in readiness for action, charged with hot water. If, from any cause, the water in the boiler falls below the proper level, the apparatus becomes charged with steam, which fills the chamber previously occupied by the water. The enclosed mercury, subject to a greatly increased temperature, is expanded, and it rises; and, coming into contact with a platinum wire suspended above it, completes the electric circuit, and sets the alarm-bell ringing. The ringing continues until such time as the water in the boiler has been brought up to its proper working level, and the tube becomes recharged with water. With the lower tem-

perature of the water, the mercury is lowered in temperature, and it sinks accordingly. The electric circuit is broken, and the alarm ceases. The alarm is conveyed by wires to the manager's office as well as to the engine-room.

Mercurial Gauge.—Where a "Bourdon" gauge is not used, some boilers are provided, as a check upon the safety-valve, with a U-tube (Fig. 15), containing mercury, open at one end to the atmosphere, and at the other end with the steam in the boiler. This gauge is only employed when the pressure is a few pounds above that of the atmosphere, and it requires careful using, otherwise the mercury may be blown out. There is not any danger attending it, as the bore in the tube is too small to allow of any sudden reduction of pressure. Steam is admitted from the boiler by the pipe *c* and presses upon the mercury contained in the tube M *b m*. Each 2 inches of rise is equal to 1 lb. pressure above the atmosphere, which has access to the top of the mercury by the open end of the tube. A line from the float in this tube passes over the pulley *p*, and

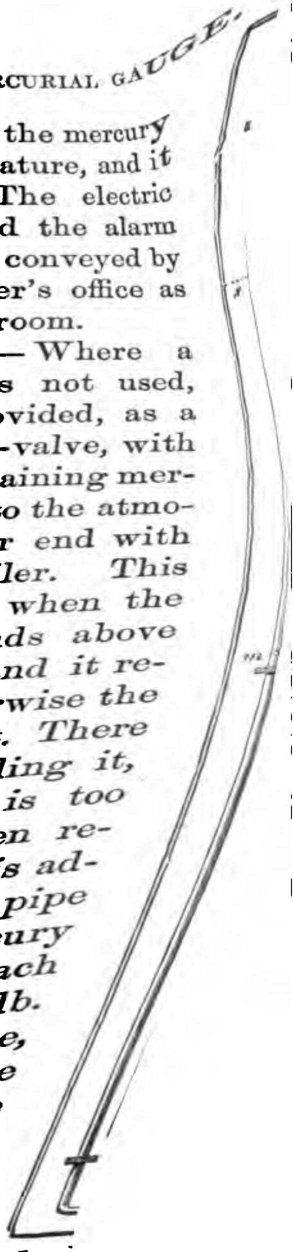


Fig. 15.—

is attached to the index S, to show the variation of pressure on the annexed scale. M, *m*, are openings fitted with suitable screws, which can be removed for the admission of mercury, which is poured in, until it shows itself at M, *m*, in each limb of the siphon. When these two holes are screwed up, the screw R is withdrawn, and a small quantity of water is poured on to the top of the mercury and the hole is screwed up. The water is provided in order to prevent the mercury from being oxidised by the steam.

Vacuum-Gauge.—This gauge consists of a case, about seven inches in diameter, with a dial-plate in front. Inside the case, and communicating with the condenser by means of pipes, there is a bent hollow tube, oval in section, the other end of which is closed air-tight, pointed off and attached to a sector which works into a small pinion, the spindle of which carries a pointer working against the dial in front. In the steam-gauge the pressure of the steam within the tube tends to straighten it; but in the vacuum-gauge the pressure of the atmosphere outside of it tends to compress or bend it, and thus move the pointer, which indicates the amount of exhaustion or vacuum.

Pressure in the Condenser.—The vacuum-gauge, like the steam-gauge, does not of itself indicate what *pressure* there is in the condenser. To find out the amount of *back-pressure* the difference between the reading of the vacuum-gauge and that of the barometer must be taken. Thus: Vacuum by gauge $26\frac{1}{2}$ inches, barometer 30 inches, then 30 inches $-$ $26\frac{1}{2}$ inches $=$ $3\frac{1}{2}$ inches, and this gives $1\frac{3}{4}$ lbs. per square inch, the absolute pressure in the condenser.

Barometer Gauge.—This instrument is employed for

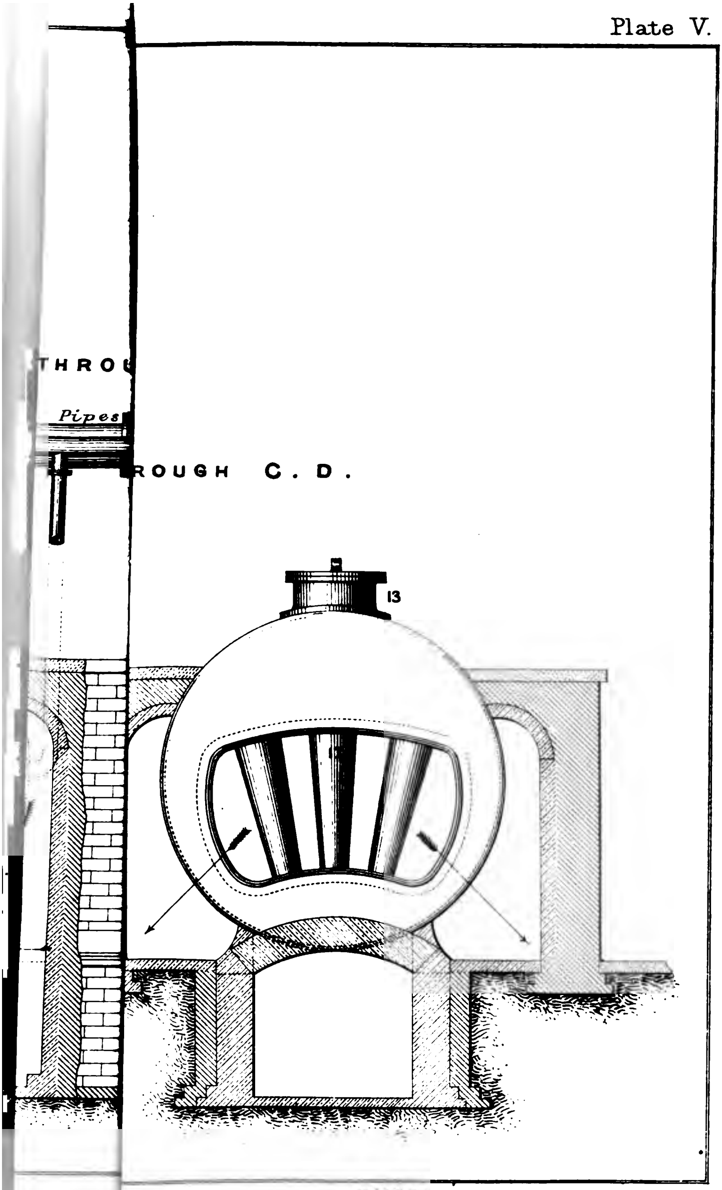
the purpose of ascertaining the pressure o
sphere. It was invented by Torricelli, t
problem respecting the rising of water in
It consists of a graduated tube of glass abou
long. The tube is first filled with pure mer
end is sealed—and inverted with its open en
also containing mercury. The pressure of the a
upon the mercury in the cup prevents the
the 30-inch tube from rushing out, and henc
the atmosphere is equal to supporting the p
column of mercury 30 inches high, or, what
thing, a column of water 34 feet high. In t
tion of the barometer, the principal object to
is a perfect vacuum in the upper part of th
obtain this, the tube must be made perfect
moisture; it must have a bore sufficient
render the influence of capillary attraction
the mercury employed must be purified by d
when a portion may be put into the glass an
it. Then more mercury is introduced and boi
tube; and so on until the tube is full, and t
contents boil. Thus the air in the tube is go
as each portion of mercury is poured in. T
should, in fact, be a little more than 30 inches
that when it is inverted, as already described, t
cury will adjust itself to the precise height (30
by flowing out of the tube into the cup, a
but a small vacuum will be left in the top of t
We learn from the fact of the air supporting
cury in the barometer that the normal pressu
atmosphere is 14·75 lbs. per square inch, or
numbers 15 lbs. A species of barometer is s
used as a vacuum gauge. It consists of a U-

taining a portion of mercury in both limbs. When the instrument is connected with the condenser in action, the mercury rises in one limb and falls in the other. In such a gauge, an inch of rise or of fall must be read as double the gain or loss, when compared with an inch of the straight one. The graduations in the common steam-gauge and the common vacuum-gauge are marked from atmospheric pressure; the one upwards, the other downwards.

The steam-gauge shows the pressure of the steam only, and therefore we must add the pressure of the atmosphere (15 lbs.) which is shown by the barometer to give the actual pressure within a boiler; the vacuum-gauge shows the pressure of the atmosphere below its normal pressure, and when it has been so rarefied as to be incapable of supporting 30 inches of mercury. The air may be so reduced as to form a perfect vacuum; although this cannot be accomplished in a condenser containing even the slightest amount of vapour.

Vacuum is expressed as so many Inches.—Gauges are graduated to correspond with a column of mercury 30 inches high, which balances the weight of the atmosphere, and is equal to 14·75 lbs. or 15 lbs. Suppose that there is a vacuum of 20 inches. That would signify that the pressure of the atmosphere above the pressure in the condenser would support a column of mercury of 20 inches vertical height. To find the pressure of vacuum, subtract the reading of the vacuum gauge from the indication of the barometer. For instance, 20 inches vacuum = 10 lbs.; 30 inches vacuum = 15 lbs. Then 15 lbs. — 10 lbs. = 5 lbs.

Thermometer.—This instrument is used to ascertain the temperature of water or other hot bodies. The



Thos Kell & Son, Lith. 40, King St Covent Garden.

thermometer was invented by an unknown author in the seventeenth century, and improved by the Floren- tine academicians. It received subsequent ameliora- tions at Sir Isaac Newton's hands.

This gauge is partially filled with mercury, like th barometer; but, unlike the barometer, it is close both ends. The bulb and a part of the tube cont mercury, the rest of the tube is vacuous, and affo space for the expansion of the liquid. A gradua scale is attached to the tube to indicate the expan of the mercury. Mercury does not take the solid f until it is cooled 39° below 0° Fahr., and it boils a temperature of 650°. This extreme range of flui renders mercury a capital register. In the Fahren thermometer, used in Britain and America, the nu ber 0° on the scale corresponds to the greatest deg of cold that could be artificially produced when thermometer was originally introduced. The freezi point, 32° F., corresponds to the temperature melting ice, and 212° F. to the temperature of pu boiling water—in both cases, under the ordinar atmospheric pressure, each division of the thermomete represents 1° Fahr., and between 32° and 212° there are 180°.

CHAPTER XI.

STARTING AND WORKING AN ENGINE AND BOILER.

[B]EFORE making a fire under a boiler, or starting an [en]gine, it is necessary to know something of their con[di]tion. This implies a general inspection; and without [ma]king this the first point or leading duty, there can [be] no confidence, and everything must be left to blind [cha]nce, in the absurd belief in one's luck. Thousands [of m]ishaps have occurred simply because an engineman [exp]ected to find an engine and a boiler in the same [cond]ition in the morning as when he left it over night, [whic]h is presumption.

[W]hat should we think of a man, the captain of a [ship,] leaving port without ascertaining if he would be [able] to keep sailing after he made a start; without [looking] round and exploring, under a due sense of re[sponsi]bility; without entertaining the slightest concern [about] the inconvenience that might arise from having [to put] in the Bay of Biscay because his cargo was [stowed] loosely; who looked on the course of events as [a] paradise?

[If a r]esponsible engineman sows anyhow—by halves, or unsystematically—he will be sure to reap [bitte]rly. It is as true as gospel. If we read actual [l]ife as we read books, we should learn the

lesson, and should store it in the memory for future use.

Inspection of the Boiler.—No inspection is worth the name that is not thorough, no plausible scheme will do as a substitute. The boiler-house is crowded with circumstantial differences. There are imperfections in construction, and there are growing imperfections, which for a time lie deep enough to weaken, but not deep enough to be detected casually. From the hour a boiler is set to work, it is acted upon by destroying forces more or less severe and uncontrollable in their work of deterioration. These forces may be distinguished as chemical and mechanical. In most cases they operate independently, yet they are frequently found acting conjointly in bringing about the destruction of the boiler, which will be more or less rapidly effected, according to circumstances often difficult to detect.

Breakdowns and failures of every possible description, like everything else, have their causes and their origin within reach of investigation. Perfect enginemanship may consist of numberless qualities and shining talents, but that engineman is perfect who has acquainted himself with the hidden dangers which lie latent in the machine, and stored the memory with facts and incidents bearing upon every mishap that can overtake him in the course of his duties.

The first thing that demands attention is the water in the boiler or boilers. The engineman should ascertain whether the level as it appears shows correctly the height of the water within the boiler, by opening the lower cock of the gauge-glass. If he is satisfied that the boiler is safe, he should closely inspect the cocks

belonging to the gauge-glass, as they are apt to become fast by the deposit of impurities from the water. The gauges for ascertaining the level of the water within the boiler are of various designs, viz. the brass cocks, the glass water-gauge, and the float. The brass cocks are of the simplest design, and they are of the ordinary description, plug and shell. They are screwed into the boiler, one above the other, to indicate the height of the water; the lowest is placed in such a position that so long as the water is visible in the glass it is not actually unsafe, although when this bottom cock is opened and no water appears the boiler is in danger. The second cock, the one above, is usually placed at the best working level of the water. The third cock is placed higher up, and is placed in such a position as to show when opened an excess of water in the boiler, and how much water should be discharged from it. When the water is below the level of either of theselast two cocks, the fact can only be known by opening them and allowing steam to issue.

The glass water-gauge was introduced by Mr. Napier. It is a simple contrivance, by the use of which the necessity of employing gauge-cocks is avoided. There are two cocks communicating with the boiler and with a vertical glass tube of sufficient strength, with only a small bore ($\frac{1}{8}$th), the better to withstand the force of the steam. The cocks being opened, and in communication with the boiler, by a principle in hydrostatics that the surface of all water in different vessels in free communication with each other is at one level, the water rises in the glass to the same height as it is in the boiler. When the boiler contains steam it is very necessary to see that both cocks are in com-

munication with the boiler. For instance, if the top cock was not open, and the bottom cock was open, the weight of steam on the water within the boiler would push the water up the glass to the top, or would at least only be prevented from doing so by the air above the water within the glass tube. Therefore, when enginemen test the water by simply opening the test-cock on the waste-water pipe, it does not give positive evidence whether the glass is working right or not. To show the level correctly, the upper end of the glass must be open to the boiler as well as the lower end, so that there may be the same pressure of steam on the water within the glass as there is within the boiler. If there is the slightest difference it will cause a higher level of water to be seen in the glass than what there is actually in the boiler. It is then necessary that the steam-way and the water-way should be kept properly opened. This is troublesome when these passages are small. They are generally about $\frac{1}{4}$ of an inch in diameter; they should be at least $\frac{3}{8}$ to $\frac{1}{2}$ inch.

Float.—This is a simpler instrument than a glass-gauge, but it has many defects, and liable to stick, either through being packed too tight or becoming oxidated, but its greatest defect is its sluggishness and want of sensibility. By inspecting these cocks as soon as he arrives on duty, an engineman in no small degree has secured not only peace of mind but a safe boiler to work with—at all events to start with, and it is an old saying and a true one, that a good beginning makes a good ending.

The next object of notice is the pressure-gauge. The boiler may be safe for water and unsafe with an excess of steam. A glance at the gauge should show what

pressure of steam there is in the boiler. Now, it is possible to make the inspection we have noticed and yet miss an important point, and one which is most likely to teach an engineman something he could not otherwise discover. When a boiler is left on over night it contains so much water; and the next morning there is not quite so much, owing to the water having fallen in temperature. During the period that a boiler is perfectly tight and sound, the amount of water said to be lost never varies; but if the boiler is not sound, but leaks, either in the flues or the tubes, the amount of water which has run off from the boiler through the defective joint or fracture in the plate should be a warning to the engineman the next morning when he inspects the water-level. By this means he may be apprised of a rent or a loose rivet long before there may be any absolute danger at hand, or before he can hear the rivet leaking. Such painstaking does not cost much every morning, but it assists an engineman to obtain a clue to what is going on in the dark. In the full persuasion that the boiler is leaking somewhere, he timely seeks to apply the remedy.

Fire-Grate.—The available quantity of heat that can be produced from a ton of coal depends upon the condition of the grate in which it is consumed. Taking coal of superior quality and the grate in an inferior state, the efficiency of the coal, in water evaporated, may fall twenty or even thirty per cent. The type of grate for the best service is one with a good bridge, not too far from the door; bars of an equal length, and not too wide apart, and an ash-pit void of ashes. It is the practice of some enginemen to pull some bars out in

order to drop the fire; but it is liable to many objections, and the greatest objection is that the fire can be cleared or withdrawn without doing so. When such work is required to be done, the refuse should be drawn into an iron wheelbarrow, and deposited outside the boiler-house, and slaked with water. Carelessness on the part of the fireman in not keeping the bars well covered and forcing the fire at another place to make up for it means a loss. It is no exaggeration to state that boilers and furnaces can be made, by mismanagement in the boiler-house, to blaze away fifty per cent. of the fuel without any advantage.

The amount of heat lost by the hot ashes may range considerably when their condition is unsatisfactory. In a large factory with limited boiler power, all the heat is wanted, and where large cinders can drop through the bars a large quantity of cold air can go through into the fire.

It is the practice in some places never to renew fire-bars until a new whole set is wanted. Day after day some hundredweights of coal are wasted for the sake of the system. That system is best which saves fuel.

The safety-plug, or lead-plug, in the boiler, or boilers, should receive its due share of inspection; and to guard against any mistake being made it should, when the boiler is empty, be withdrawn from the plate, and, if necessary, refilled. Plugs are often left in until the lead or the alloy is perished in them and they stop themselves, and sometimes a factory full of hands. Three months is quite sufficient time for a plug to be left in without renewal of the metal. By inspecting plugs every morning, due notice is obtained of their disposition to break. Leakages should be stopped at once, as

corrosion, and to destroy the plate

that the blow-off cock should be in
rder, working freely and conveniently
.thout leakage. With a tap one may
when it is shut properly. With a
orking with a wheel or a screw, leakage
detected. All valves of this description
with indicators to show when they are
Iany a boiler has been ruined through
oing noiselessly out of the boiler, in con-
blow-off valve not having been screwed
on the seat.

valves upon the boiler should be clear to
boxed up or placed inside a pipe, up
am escapes to the atmosphere. This is
cement to blow off steam. The practice
down the valves should never be coun-
It is also a favourite dodge, to hold the
boiler, to pile some weights on the lever
-valve, and although it is not so wicked an
ing it, still it is the right way to blow the
By an inspection of the lever the practice
ected. The valve should be allowed to blow
er to test its correctness with the pressure-
t with moderate care it may be kept quiet
est of the time. When a safety-valve is
off, and the engine is at work, the boiler

p-valve on the steam-pipe should be opened
tly, to give the metal sufficient time to expand;
n should be allowed to pass it with equal care,
to warm the pipes gradually. By suddenly

turning on the steam, a stop valve-box was burst, not by steam pressure, but by the expansive force of heat unequally applied. Great care should be taken in opening all valves in connection with boilers, so that the pressure may come steadily on the pipes and cylinder; as, if there should be water in the pipes, the steam may drive it against a bend with sufficient force to split it. The same care is recommended when shutting off a stop-valve. A fearful explosion once occurred by shutting a communicating stop-valve too suddenly. Two boilers were opened into a third to blow out the water, its own steam having fallen too low for the purpose; when this was done the top-valves were closed, and both boilers blew up. The whole force of the steam was stopped in its motion, and the recoil from the valve struck back forcibly into both boilers and burst them. The same recoil takes place when the flow of water is suddenly stopped by a cock or valve. An engineman had been blowing down a boiler, but after doing so he found that he could not shut the cock on the boiler; he shouted to his mate to shut the "blow-off," and the recoil of the water and steam forced a small oak wedge out of the cock, which had been left carelessly in the boiler.

Neither in starting nor in stopping engines and pumps should the flow of steam or of water be interfered with suddenly.

Experience proves how little notice the destructive power of sudden expansion receives amongst unthinking enginemen. They know practically that if hot water is turned into a glass, the chances are that the glass is cracked; but, unthinkingly, they turn steam into cold pipes, cold cylinders, and cold condensers,

and when these break, the cause is declared to be unassignable. The cause is the same—the sudden admission of heat into a cold vessel; the effect is the same—a smash.

Before starting the engine, it should be seen to be disconnected from the machinery it is intended to put into motion, or the machinery should be ascertained to be fit to be moved. In either circumstance the engine itself should be examined, lubricated, and drained of condensed water.

In conducting an examination, it is well to remember that it is not big things, such as fly-wheels, cranks, and beams, which generally give out; but the smaller parts of an engine, such as bolts and nuts, keys, and tiny split-pins. The examination should be conducted systematically, and not directed to any particular thing that may happen to be thought of at the time. The whole of the engine requires to be examined before it is started. The examination should commence at the crank shaft.

Big-end.—The big-end brasses work best, wear longest, and knock least, when tightened up brass to brass. They are, otherwise, adjusted by means of a cotter, key, and a set-pin. When this plan is followed, the cotter and key are not fast. The set-pin used to keep them from shifting is liable to be slacked back by jars. But when the big-end brasses butt together, the cotter or the bolts for holding them can be driven to nip them tight, and thus may make a solid connection. When bolts are used, holes should be drilled longitudinally in them, in order to reduce their sectional area approximately to an equality with that at the bottom of the thread, so as to render them uniformly elastic.

Excentric.—The sheaves are generally of cast-iron, and the strap of wrought-iron, or it may be of cast-iron. The sheaves are keyed to the crank-shaft. The hoop or strap is always in two halves, held together by bolts and nuts. They should nip tightly together, because any slackness would interfere with the lead and the working of the valve.

Crank-shaft Bearings.—The brass bearings are fitted into plummer-blocks, which are bolted to the engine-bed. They give very little trouble, provided they are properly oiled. Should one, however, get heated and cut the bearing, or should it wear away faster than the other, it throws a very ugly strain upon the crank-pin—one likely to break it. As the bearings wear down, they are prevented from knocking by chipping a little off the upper brass, or by reducing the distance-piece between the brasses. But at all times the shaft should be maintained perfectly level.

Glands.—The most important point about glands is to see that they stand fair or square with the rods which are guided by them; and that there is sufficient packing in the stuffing-boxes to keep the steam from blowing through.

Trimmings.—The trimmings are generally made with worsted and a piece of copper wire; and they supply the various bearings with oil by capillary action. The trimming is made by placing the worsted of the requisite thickness on the middle of a straight piece of copper wire, which is then doubled and plaited several times to bind the worsted just sufficiently to hold it. The trimming is then placed within the siphon-pipe and pushed down into a position just clear of the axle, whilst the ends of the worsted lie in the oil.

This trimming will supply oil as long as there is oil in the cup; and, therefore, when the engine is stopped, the trimming should be pulled out of the siphon-pipe, and placed on one side in the cup. There are several circumstances to be noticed which, in the use of trimmings, operate disadvantageously.

The trimming may be too tight in the siphon-pipe; the cotton may be choked with tallow; the cotton may be wet or worn out.

Oiling.—The piston-rod packing is exposed to the heat of the steam; and, therefore, it should be lubricated with tallow, likewise the cylinder and the slide-valve spindle. Main bearings, such as those of the crank-shaft, the beam-centre, the crank-pin, and the excentric-hoop, demand special attention; for the renewing of such bearings, when destroyed by neglect, involves a considerable loss of time and money, to say nothing about the vexation. Amongst other points, there are the cross-head and guide-rods of the pump, which should be swabbed with oil: oil is better for the purpose than tallow, and the pump-top may be kept clean. The pump-gland requires no lubrication other than that which is effected by the passage of water.

Geared-wheels may be kept cool, and the wear reduced to a minimum, by using a lubricant composed of a mixture of black lead and tallow; which also keeps them from making the peculiar squeaking noise, which arises from their being allowed to run dry.

Another thing requiring attention is to see that air can enter the siphon-cups. If it cannot, lubrication is arrested. By the access of air, atmospheric equilibrium maintained.

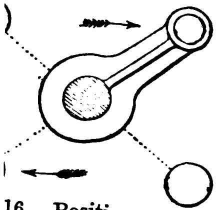
When the boiler and the engine have been thoroughly

overhauled, and the engineman has satisfied himself that there is nothing in the way of the engine or the gearing—as blocks of wood thrown about, or waste amongst the teeth of geared wheels—he should proceed to expel the air and condensation-water in the cylinder. In a non-condensing engine this is effected by opening the cylinder-cocks and admitting a little steam into the cylinder until it is warmed and dried. The operation is very simple; but it is not so simple for a condensing engine, and, therefore, we will confine ourselves, as the operation is more complicated, to the starting of an engine such as requires the most skilful enginemanship. The first operation is to admit steam to the jacket which surrounds the cylinder; the steam warms the cylinder, and when it issues sufficiently dry through the waste-pipe into the condenser, getting rid of all the air and water in the cylinder and steam passages, then the blow-through valve may be opened to eject any air or water that may be in the condenser.

If the blow-through valves and the injection-valve are closed, the result will be a vacuum, shown on the gauge. If not, then the process is repeated until a vacuum of 5 inches or 6 inches is obtained. This amount of vacuum is ample, and it may be attained without incurring the risk of heating the condenser or the air-pump bucket. If the bucket be suddenly expanded by heat, it becomes fast, and the result is likely to be a bent air-pump rod to begin with. These preliminary operations are effected by working the hand-lever, whilst the excentric-rod is disconnected.

All going well, the engine is moved round a few revolutions by hand, by means of the starting or hand-lever; or the hand-lever is used to move the slide-

ves up and down, to distribute steam on both sides he piston. By this operation the engine is set in tion. Great care must be taken that the engine s not stop on the centre. With a large engine this incident happening is not creditable; nor is it a comfortable performance to pinch her off. The crank may be in the position shown in Fig. 16, when the end of the excentric-rod should be dropped into gear. The starting bar should be at the same time taken out of gear; if not, it may knock a



16.—Position of the rank at starting.

over before he is aware of it. Much care is d at first, especially at starting, to see that the e is not flooded with water. If the injection is done, the air-pump bucket may not be able to the condenser, and the water rising into the er may break the beam in halves.

out in a gauge-glass.—When a gauge-glass breaks, r should be at hand already cut to the required . The length should be such as not to allow ass to interfere in the least, either at top or , with the passage into the boiler. The glass , cut with a triangular file. First, wet the file, e glass tube with the first finger and thumb at ce where you wish to cut it; draw the file and lightly two or three times backward and ; if the file is pressed against the thumb-nail left hand, the file will be kept on the same place glass; the file will mark the glass. Take the en, in both hands, the hands being an inch

or two on either side of the scratch, then attempt to bend the glass, and it will break across at the file-mark, which weakened the tube. Another way: the tube may be cut by inserting a small round file, or the end of one, within the bore, to the point where it requires to be cut, and then scratching it all round with the point of the file, keeping the file in the hole; break the piece off, by holding the tube still in the left hand and depressing the right. Hold the tube in a cloth, or a piece of waste. Very serious accidents have happened by pieces of glass entering the fingers. The power of sensation and use of a finger have been partially lost by such an accident. After all the old packing has been cleaned out of the sockets, blow the passages out by steam to clear them of broken glass, hemp, or india-rubber, and then put the glass into its place, taking care to measure again and see that it does not interfere with the passages into the boiler. Before inserting the packing a small piece of wood should be placed on the top of the glass tube, and held down by screwing the top nut round a few times; this will prevent the glass being lifted whilst the top is being packed. Accidents of a serious character have happened through the glass having being lifted up, when packing, so as to lap over the hole into the boiler. With the precaution noted above, such an occurrence cannot happen. The communications with the boiler should be opened gently, so as to warm the glass by degrees. If hot water or steam is turned on suddenly, the glass will snap by unequal expansion.

When a glass is burst, the water should be turned off first, and then the steam. When your hand is on the water-plug, the steam from the upper hole is partially

before it reaches your hand. But if you am first, the escaping water will scald.

—This is caused by the lateral frictional ıe steam against the globules of water, as it ıpwards to the surface of the water, and ;ting in motion and drawing upwards much h is borne along by the energy and velocity ing steam into the pipes and cylinder, just f nut-brown leaves lying under an oak-tree .long in the current of the passing wind. natural cause of priming. The principal priming is deficiency of steam-space in the he want of a good head of steam. This defi- ; always traceable to faulty construction of ıt may arise from mismanagement. Steam- her be diminished or enlarged by adjusting he water within the boiler. When a boiler vater there is no steam-space, and its capa- ɔlying dry steam is practically diminished. ; the steam-space is limited to the interior ɔipes and the steam-chest. If they have acity sufficient to hold as much steam as ylinder twenty times or more, the evil of a boiler full of water is proportionately ɔmpared with the bad effects of small ıose parts. Steam-space is required to steam, so that in the discharge from ;he cylinder the pressure in the former n any considerable degree, and that the ;hall not exhibit any considerable fluc- re there is only a short run of steam- n-space is absolutely confined to the en that is so, as much room as possible

should be found for the steam above the water. The best preventive of priming is a good head of steam.

The water in the boiler has always a tendency to rise with the steam near the opening for steam to the cylinder. This tendency exists in proportion to the fluctuation of pressure at each stroke of the piston, which is caused by the steam moving from the steam-chest into the cylinder, and the steam in the water rising to the top receiving a sudden impulse, to take the place of that withdrawn to work the engine. This impulsive motion signifies collision and confusion in the mixture of steam and water. Instead of there being a uniform rising of steam, and a uniform falling of water to the hot plates, there is an intermittent action — explosive violence alternating with calm inaction. Steam-space prevents this, if due care is taken to keep the pressure up.

Steam, when used to produce power, varies in value according to the pressure. The greater or less elasticity of steam is not the effect of its density alone, but also of its expansion by the free caloric, or heat, which it contains.

The pressure in the boiler should be maintained just below the blowing-off point, and the throttle-valve least opened, so that the steam may be highly elastic, for in proportion to its elasticity so is the gain in mechanical effect and in economy of fuel; but when the pressure is allowed to drop, the head of steam is reduced, and instead of the valve cutting off at, say one-third of the stroke, it must, in order to keep up the speed of the engine and machinery attached, cut off at half-stroke, and the fluctuation of pressure caused at each stroke increases the ebullition of the

water near that point of the boiler whence the steam is drawn. The ascending currents of steam which are disposed to fill the steam space are in most violent action, and they by lateral friction lift a large quantity of water in the form of spray. Not only so; when the induced current is sensibly felt in the boiler, particles of earthy and other foreign matter are carried up into the steam-pipes and conveyed into the cylinder, where, in conjunction with oil or grease, they cut at every stroke into the face of the valve and the cylinder. In boilers using dirty water, particular care is required to keep plenty of steam *waiting* for the cylinder; for if the supply is short, and if it is used as soon as it is made, it will certainly carry away with it the scum and dirt floating on the surface of the water, and the dome, pipes, steam-chest, and cylinder-ports will be plastered with mud.

Whatever system may be adopted for holding back the particles of water, no system succeeds, where the boiler-power is limited, like an internal perforated pipe fixed near the top of the boiler, and close to the supply-entrance to the cylinder.

The aggregate sectional area of the perforations in the pipe should exceed the sectional area of the pipe. By this plan the amount of spray carried off by the steam is minimised; and if it do not altogether prevent priming, it is an invaluable check upon such violent local ebullition as takes place when the steam is drawn from one point, and especially if that point is over the furnace. Sometimes a dome or super-heater is added, for the purpose of preventing priming; it simply increases the steam-space. In some cases the steam-space is increased with excellent effect by taking out

the top row of tubes, or even two rows; this improves the circulation of the water and free escape of steam, and instead of being a loss, by the decrease of heating-surface, it becomes a gain.

No amount of steam-space or of ingenious mechanical arrangement will suffice to regulate the action of the steam if there be not a thinking head in front of the furnace to insure regular firing. Some enginemen can work boilers well which others have given up as incurable primers; but there are enginemen and enginemen.

Now, a boiler is not always in the hands of owners who are willing to make alterations; and therefore an engineman who is equal to his work will, with a ticklish boiler, conduct the firing with great regularity. Any boiler can be made sensitive and hard to manage. Fire it on no system, feed it with water, just as the lead-plug is in danger, and fill it to the whistle, and your boiler will one day give a big kick. Irregularity of firing is easily prevented where there is a will. The smaller the steam-space, the greater the regularity that is required.

The rapidity of the ebullition occasioned by a small addition of heat may be witnessed experimentally by applying a piece of lighted paper to the bottom of a kettle containing boiling water. The heat will be rapidly taken up, and the ebullition will become most violent even upon so small a scale.

Ebullition consists in the forcing upwards of partic[les] of water by colder particles: a due succession of s[…] particles ascending and descending is necessary to [take] up the heat from the heated plates. The sole mo[tive] power is the diminished specific gravity of the [...]

heated plate. After ebullition has
.e time, the rising globules of water
ıal power, and the slightest addition
ıbove that of the surrounding mass,
› force its way upwards through that
ıg in motion a body of water, the
is continued by the induced current
ɔowards the cylinder. Hence, again,
ɔy an injudicious excess of heat sud-
the furnace crown plate, or tubes.
ıes takes place by mixing waters of
gravity. If greasy or soapy water is
a boiler, the grease, surrounding the
the passage of heat, and they are able
ıeroidal state until they are heated to a
nperature than ordinary water requires
When their evaporation is effected, it
ɔe, and the steam inside the film of oil
›eak, overheated, rushes upwards when
meeting greased round globules of water,
lateral friction, it puts all into motion,
and priming becomes heavy.

priming commences all the drain-valves
nder should be opened, the engine should
rn, all the feeds put on, and the furnace-
. until the water becomes steady in the
furnace-door should only be opened in
s.

several advantages in a liberal steam-space.
team-space is large in proportion to the
eam used in the cylinder—and the propor-
should be regulated by this—the pressure
the boiler exhibits no considerable fluctua-

tion, the pressure of the steam does not perceptibly fluctuate, as it is being drawn in intermittent quantities to the cylinder. In locomotive boilers, however, it is not an uncommon thing to see the needle of the pressure-gauge working or vibrating upon the joint when the steam is being discharged into the exhaust-pipe, through the cylinder, as fast as it is possible for the boiler to supply it.

In ample steam-space there is a provision against the results of any relaxation in firing, and steam is kept up with much greater regularity, and without any waste of fuel—unnecessary waste. Where the steam-space is cramped, the fire is generally urged by a strong draft, and the gases in the furnace are consequently hurried along the tube, or tubes, before they can part with anything like the proportion of heat which they are *capable* of transmitting to the water. The gases *obtained* by chemical combination in the furnace, or fire-box, part with their heat as they fly along the passage to the chimney. They possess a gradually-diminishing amount of heat, as they leave from the bridge, or tube-plate, until they unite with the open air. As they pass each inch of heating-surface, they give up a portion of the heat which they have in excess, in virtue of the excess of their temperature above that of the surrounding plates. But the proportion of heat given up depends on the time during which they are in contact with the cooler body, the boiler.

CHAPTER XII.

MANAGEMENT OF THE FIRE.

COAL; what is it? Three generations back Erasmus
Darwin came to the front, and maintained that coal
'as formed out of ancient morasses and forests. Sub-
quently, full and accurate information was dispensed
›m the laboratory respecting the chemistry of coal;
the development of the principle on which perfect
bustion is achieved, belongs to more recent times.
consists of decayed trees, which lived and grew
hundred feet in height, and even more. From
it is justly inferred that this country was once
'ed with a tropical climate.

the feet of these gigantic trees, there grew
c ferns, and the roots of both were bedded in
hich, in process of time, became mud banks,
ı mud hills, formed by innumerable tides in
times. As these banks had once stood high
then were buried during a succession of ages,
a succession of ages they were left high and
The finding of organic remains at the base
pex of the coal rocks shows that their
rsion has taken place since the creation of

tion from the state of living woody tissue

to the mineral coal, does not admit of doubt, for the impressions of the leaves and stems of ferns and trees are clearly discernible in numerous instances in coal of a stratified character; but the precise conditions under which the decaying woody matter became so largely bituminised in its conversion into coal have been but imperfectly made out.

Practically, there is much around us that is intricate and mysterious, but much light has of late years been shed from out of the laboratory, which has, in more ways than one, given us to understand scientifically the elements with which we are surrounded, and their influence upon each other.

The chemical union of air with the compound mixture in coal, as we know it, was at one period an association that entered into few men's heads, and the conditions of the evolution of light and heat, by the contact of gases with each other, were outside the pale of popular intelligence. Combustion was for a long time held to be the disengagement or development of a certain air, supposed to have been contained in all combustible bodies, and to which the name of phlogiston was given, and those bodies which had undergone combustion were said to be dephlogisticated, or to have given out their phlogiston. This hypothesis was held in the face of facts at variance with it, for it was well known that metallic oxides formed by combustion increased in weight, which could not have been the case if combustion consisted in depriving a substance of one of its constituents. It was not surprising, t that philosophers differed upon the point, nor str that Lavoisier should have made the brilliant that light and heat could be caused by o

the moment of its fixation with a combustible r.

any elaborate analyses have been *made by* eminent to ascertain the constituents of coal; and analysis that the principal ingredients are carbon and gen. There are other minor ingredients: oxygen,

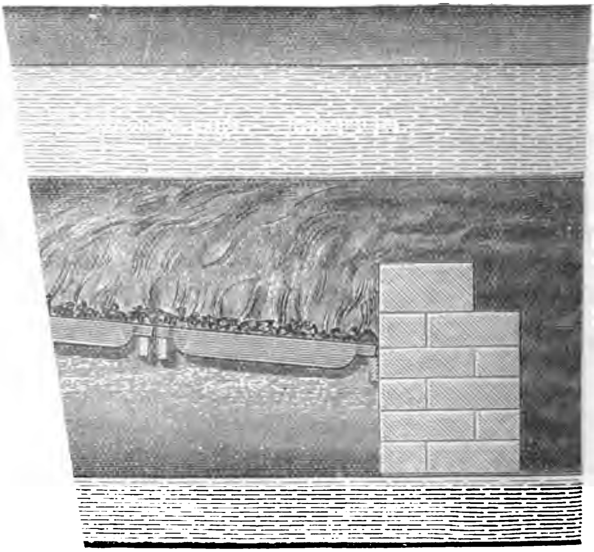


Fig. 17—Imperfect combustion.

ır, and ash, which determine the econo- coal for raising steam; but, without he specific importance of these elements be stated broadly that it consists of arbon and 5 per cent. of hydrogen. ate, these elements are united as a aracters and modes of entering into

combustion are very different. The hydrogen is the first to take fire, and it burns in a gaseous state; the carbon is combustible in a solid state.

The application of heat is necessary to start the process, and there is no stage, from the time the fire is lighted until it is practically giving out an intense heat, that does not depend for its advantageous effect upon two cardinal conditions, namely, saturation and temperature.

The natural law is that combustibles become saturated with oxygen in certain fixed proportions, to form certain chemical products of combustion; and that can be accomplished only when the right temperature prevails.

On the application of heat to coal, the fire at first may be seen to be nearly all smoke; this consists *mostly* of hydrocarbons, in which hydrogen is in com*bination* with carbon. After the fire is sufficiently heated or ignited, or, which is the same thing, when the temperature is sufficiently high, and the fire-door is shut close, water—the product of combustion of hydrogen with oxygen—coloured with carbon, will be found in abundance about the furnace. Some persons, witnessing this natural result, not knowing the true cause, have ascribed it to the sweating of the iron. So long as the same temperature is maintained, and the same amount of air admitted, for every ton of coal, half a ton of water and more can be formed by this process. Now suppose that, by opening the apertures for air, the smoke vanishes, then the hydrogen and the [illegible] are receiving their proper quantity of air necessary for ox[illegible] ma[illegible] combustion perfect. The furnace is now *in* [illegible]mperature, and the proportion of air admit[illegible]

greater in quantity, and so the conditions are such as are necessary to form carbonic acid.

Carbonic oxide is formed when combustion is imperfect, and carbonic acid when combustion is complete. If the air is deficient in quantity, large volumes of smoke pass away into the chimney. This

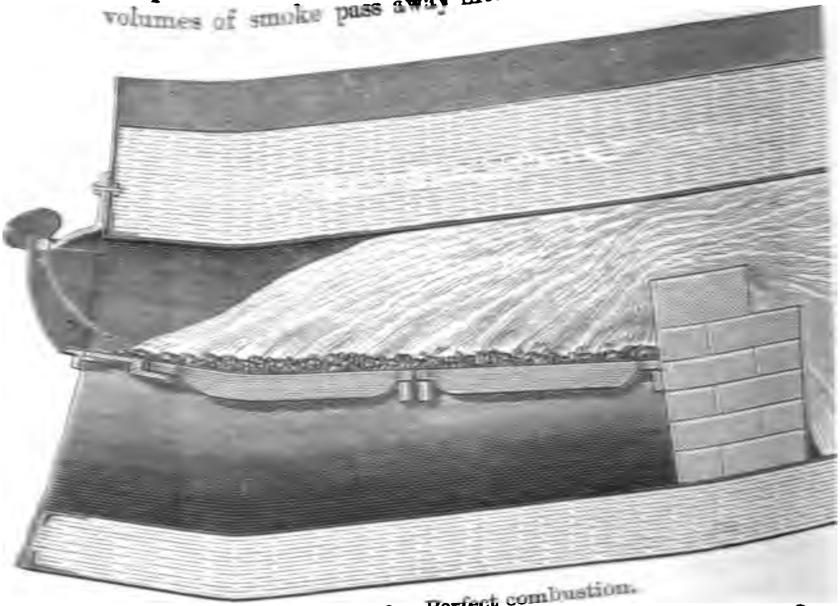


Fig. 18.—Perfect combustion.

smoke contains the distilled essences of the fuel, and, being heavily charged, it lounges on its way; as they become cooler in passing through the flues, carbonaceous particles lodge there. People who do not know the real value of the carbonaceous matter, call it soot; it is, nevertheless, coal wasted. It is just as much coal, as iron-filings are iron. When air is supplied to the

furnace in sufficient quantity, the combustibles are all supplied with oxygen, and *then*, the carbon, which passed away in a state of very fine division as smoke, meeting with *its* amount of oxygen, at a sufficiently high temperature, it unites and forms carbonic-acid gas. We might call carbonic oxide an extractor of heat, and carbonic acid a giver of heat. A mass of fresh fuel thrown upon a bright fire extracts its heat, for the volatilisation of its gas from that fire, and the heat for a time is converted from the sensible to the latent state. A large volume of gas being generated, more air is required to reconvert the heat from the latent to the sensible state.

No better evidence of the necessity for supplying and intimately mixing air with fuel could be given than by the numerous plans which have been resorted to by smoke-burners. Such are split-bridges, Argand furnaces by dozens, air-boxes at the bridge, perforated plates at bridge, hot-air at the bridge, and jets of steam. Many of these plans are worthless *now*, but they mark the successive strides in the march towards the attainment of something better.

Many of the inventors were on the wrong track, and the work of the labourers in this branch of science has been comparatively unproductive, because they followed the popular fallacy—jumped in fact at the conclusion—that smoke, after it had left the furnace, could be ignited. Smoke must be *prevented* from forming as far as possible; but when formed it must be ignited in the furnace, or it will surely go up the chimney in the same condition. The carbon particles in the vapour of the smoke will not unite with the oxygen except at a high temperature. By air-boxes and like means

smoke discharged at the chimney-top was reduced, but it was not because the smoke was consumed. What was done was this: The cold air (at 60°) admitted at the bridge, on coming in contact with the heat there coming from the furnace, was suddenly raised in temperature to 1000°. When, in virtue of its increased lightness, the velocity of the draught was increased as between the bridge and the chimney or atmosphere vastly superior, as between the door and the chimney, before the smoke-burner put his patent in. The draught was improved by the newly formed current of air, whose velocity inducing a better quantity of air to enter the furnace at the door and up through the bars, produced a better mixture in the furnace of the gases; and the result was an improvement—less smoke, and a better result—*but* the smoke was not burned, as many thought it was, beyond the bridge in the tube. One of the most successful plans for inducing a current of air to enter the furnace at the door was invented by Mr. D. K. Clark. Jets of steam are introduced into the furnace above the door in combination with a supply of fresh air from the front, and are directed over the fire towards the bridge, by which the draught is considerably increased, the gaseous elements are thoroughly mixed, and combustion completed within the furnace. Provision is made for adjusting the supply of air. This plan is thoroughly effective as a smoke preventer. The steam jet, it will be seen, is the instrument to draw into the furnace, *by induction*, the necessary amount of air from which the combustibles could obtain the requisite quantity of oxygen to effect complete combustion of the gases within the furnace.

The Grate.—As to the best proportions for the grate,

they depend upon the rapidity with which steam is withdrawn from the boiler; but, although this may vary, there is one thing about the furnace that should never be neglected; and that is, that the grate should be of a length just sufficient to insure a complete mixture of the gases before they pass over the bridge, and here the ingenuity of the engineer is required. If he finds the fuel is not burned perfectly, notwithstanding the plan of side-firing—of which more presently—he may seek for the cause either in the arrangement of the grate, or the management of the draught.

In many furnaces the grate is too long. With a very long grate—say, 6 feet in length—a material proportion of the combustible on the bars, especially at the back part of the furnace, passes away into the flues without having secured the proper quantity of air for completing its combustion. This defect arises from the fact of the fuel near the door seizing its share of the air, and the formation of carbonic-acid gas, which, moving forward in the direction of the flues, is arrested by the carbonaceous gases loitering in the neighbourhood of the back part of the furnace; and the result is, a second portion of carbon is added to the carbonic acid, and carbonic oxide is formed. If this carbonic oxide cannot find the oxygen required, together with the temperature to be reconverted into carbonic acid, it passes away necessarily as half-consumed gas, and rolls away from the top of the chimney in a dark cloud of smoke. Then, with an excessive length of grate, there is the difficulty of keeping it properly covered with fuel at the bridge. For, besides the difficulty of properly distributing the fuel at the end of a grate of considerable length, the fuel burns

away faster near the bridge than at other parts nearer to the door. With a shorter grate the fire is managed with less difficulty; the draught also is more nearly uniform, and is more active in consequence of the concentration of the current on a grate of less area. Hence, also, the combustion is more rapid, and the temperature in the furnace is higher, and smoke is more effectively prevented.

The fact is, many boilers are worked as hard as possible, and economy is out of the question. When the supply of air is imperfect, it is strikingly demonstrated soon after firing by the volume of smoke discharged, although the smoke gradually disappears. Hence it is that the opening of the door a little to admit an additional quantity of air above the fuel immediately after firing usually prevents to a great extent the formation of smoke.

Can smoke be prevented?—An opinion prevails amongst firemen that if by any means, either through the bars or through the doorway, air can get into the furnace, it will, as a matter of course, arrange itself, and mix with the combustibles in a manner suitable for perfect combustion. It is a mistaken opinion. The prevention of smoke is only effected when the right quantity of air is admitted—no more nor less. Were there nothing else required—no more attention in the use of coal—than the combustion of the fixed carbon, that is the coke portion of the coal, combustion would be easily effected; but, in the combustion of coal, there is the gaseous element to deal with, to be generated and consumed. We will suppose ourselves at the front of a furnace containing a fire thoroughly burnt through, bright and cheery, whilst air is ad-

mitted through the fire-bars and above the fire. Now, what is in the furnace is as nearly coke as anything can be: it is the fixed carbon left behind after all the tarry matter has either been consumed or escaped as smoke. On a charge of *cold* coal being thrown into the furnace, it extracts heat from the fire, as a matter of course, or where would it obtain its heat? For a moment this abstraction of heat by the cold coal reduces the temperature of the furnace, and if the charge of fresh fuel is spread over the whole of the fire, it is sufficient in some instances to lower the temperature of the furnace to such an extent as to cause a boiler to leak by sudden contraction of the plates near the fire; and as this contraction is in its direction fore and aft of the furnace, it has a tendency to shear the rivet heads off and cause a boiler explosion, and if anybody examined such a boiler they would consider it was *unexplainable*, or put it down to electricity. Now, with the fresh charge a gas-generating process is set up, and large quantities of gaseous and inflammable material are given out, and unless there is an equivalent quantity of air allowed by the fireman to enter the furnace and chemically combine with them, they pass away and create smoke. The fact is, the furnace is precisely in the condition to receive air, as the relative proportions for complete combustion are wanting. What are escaping? The hydro-carbons, the very constituents of the coal which form flame, and are being carried away by the gases to be deposited on the surfaces with which they come in contact, *and if* the current is sufficiently strong, and the chimney *not* high, they will ignite on coming in contact *with* the atmosphere, as may be seen in the cas

steamers, or locomotives at night. Because these gases could not find the air they require *in* the furnace, it is seen that, when they meet with it *outside*, they instantly combine with the air and ignite. A skilful fireman, with great exactness and calculated punctuality, after he has put on a fresh charge, regulates the air, and by bringing sufficient oxygen in contact with the minute particles of carbon ascending in the gases, their combustion is effected within the furnace, and the gases, instead of being coloured black with the minute particles of carbon, ascend on their way to the atmosphere invisible, and consequently no smoke is produced.

Thickness of the Fire.—Along the sides the fire should be deeper than in the middle, having a depth of from 6 to 8 inches at the sides, and from 3 to 4 inches at the middle. These depths will be found to give good results. Near the brick bridge, the depths should be slightly increased, in order partially to meet and deflect the current advancing towards the bridge, and thus somewhat to force the air into contact with the gases.

Shape of the Fire.—The "pancake" fire is made by shovelling the coals all over the grate, and requires no skill. So long as there is a bright patch of fire to be seen, the shovelling goes on until the light is put out. This is a barbarous and wicked practice; barbarous because it is behind the times, wicked because it may burst a boiler by cooling it too rapidly, and causing an enormous amount of contraction about the furnace of a dangerous nature. It was found by the use of a pyrometer, an instrument necessary for every engine-house, that a stiff charge of green-coal would lower

the temperature of an ordinary furnace 200° or 300° in a very short time. After the coals were well ignited the temperature would rise as much as 500°, and as the fuel became low the temperature would gradually decrease about 250° until the fireman charged again, when, as already mentioned, there would be another decrease. From this it is easy to infer that the variations which take place in all the different stages of combustion consequent upon the acts of charging, stirring, &c., have a serious influence upon the furnace-plates, and also upon the safety of the boiler; and that the sudden contraction caused by firing is as liable to cause a boiler explosion as a safety-valve jammed down or out of order. There are, probably, no fractures of such frequent occurrence as those found at the joints of the furnace-plates, and these fractures are most common from the holes to the edge of the plate in the outside lap. The fracture may not be very serious at first, but it gives rise to leakage, which is generally the alarm note calling the boiler-maker. The mischief is done by local contraction in the furnace, and about the bridge. It may be stated that expansion opens and contraction closes, but if this law is applied to a lap-joint, it will be found, if suddenly cooled in an expanded state, that a great tensile strain is put upon the outside plate of the lap; the inner plate extends away into the tube, and retains much, if not all its working temperature, and the result is it resists the contracting and pulling of the outer plate, and between them they endeavour to liberate themselves by shearing the rivets off; the rivets being strong, the rivet-hole is ripped open to the edge of the plate, and under such conditions it is

contracting furnace-plate that is damaged, as a matter of course, because the temperature of the inner plate is comparatively unchanged. However good the boiler-work may be, the very best plates are soon rendered brittle, and are fractured through the rivet-holes, to the imminent danger of everybody, by bad firemanship. The pancake-fire is flat throughout, but the thickness is generally greatest at the door, and thinnest near the bridge: the air by this kind of fire is restricted where it should have free access, and where it has access it should be shut out.

The Scoop Fire.—To maintain steam, to consume as much smoke as possible, to admit as little cold air as possible, and to work coal to the highest point of economy, the fire requires to be made and maintained through the day to a form resembling a scoop.

The thinnest part of the fire should be near the door, the sides well piled up, and a good thickness of fire against the brick arch. A fire of this form is built upon the principle that air requires plenty of room to enter the furnace and less facility for leaving it, so that there may be a proper admixture of the gases, that they may be fairly ignited and at the highest temperature possible *drawn* into the tubes.

Combustion in a furnace thus conducted is more perfect than in furnaces worked with pancake fires. The mass of incandescent fuel piled against the bridge is an effectual barrier against the air rushing into the flues comparatively cold, and it is as equally effectual in maintaining an equal temperature about the ring-seams. The air, on entering by the furnace door, which should be done near the bottom, as in Martin's plan, is raised in temperature and expands, by which

its volume is increased and its velocity is accelerated. To counteract this the fire is tapered, so that the cubical capacity of the furnace for air is gradually reduced from the door towards the bridge, and therefore the air is brought into intimate contact with the gases, and a proper admixture is insured. If the mixture has been imperfectly performed in the front portion of the furnace, a more complete combustion will take place near the bridge, in the neighbourhood of the thickest of the fire.

Mode of Firing.—The greatest saving is effected by side firing and half-end firing, always leaving one side perfectly bright. This is the best practical mode for accommodating the gases and for properly introducing the requisite quantity of air.

But that is not all; there are two conditions on which complete combustion is dependent—the proper proportion of combustible gases and air in mixture, and the maintenance of temperature. Suppose a furnace-door is opened with plenty of burning coal on the bars, the steam cannot be kept up. By putting on more coal, we are as badly off for steam. The explanation is that the gases of the coal and the oxygen of the atmosphere combine only at a certain temperature. By side firing, the temperature of the furnace is maintained more nearly to the required degree than when both sides are fired at once. Further, by side firing the intermittent expansion and contraction of the plates of the boiler is considerably reduced.

Intervals of Firing.—The intervals between firings depend upon the character of the coal, the strength of the draught, and the demand for steam. Some kinds of coal will not be hurried; if subjected to a sharp draught, they fall to slack. Such is anthracite.

The best way to procure good firing, free from smoke, economical, and to keep down the coal bills, is to employ intelligent firemen.

Numerous plans have been resorted to for the perfect combustion of smoke, and for making steam out of the minimum amount of coal, but the best constructed invention is annulled unless there is a thinking head between the coal heap and the furnace.

There is required something more than shovelling if the principles of combustion are to be followed. If they are observed, who suffers? Not the shovel-man. If a man in charge of a furnace is a total stranger to the principles affecting combustion, no ingenious mechanical arrangement, no scientific apparatus, can supply the deficiency.

It has been stated that mechanical appliances for firing have a tendency to beget lethargy and to convert the firemen into machines themselves; that there is no intellectual activity required, and that the vacuity in the mind is filled with trash. In support of this view, it is said that many excellent and ingenious smoke consumers have "gone under" because the men would not take to them. If they were asked to give a reason, they would spare no trouble in telling you "it didn't suit them." There may be some truth in this. Some men pride themselves upon possessing an opinion, so called, no matter how glaringly it may be opposed to facts.

Qualifications of a good Fireman.—A good fireman is guided in his duties by three considerations, namely, knowledge of the boiler, knowledge of the coal, and a knowledge of the principles of combustion. To set down any one general rule for providing an adequate

supply of steam would be impossible unless all boilers were alike, and coal were of the same quality. A man, to bring his knowledge of firing up to the highest point of proficiency, to give the best economical results, must not only understand how to put coal on, but he must know his boilers, that is to say, the capabilities of the furnace.

He must also be a good judge of coal when he sees it, and able to tell within reasonable limits what he can do with it. There are many kinds of coal. There is a bituminous coal; there is a slightly bituminous and a semi-bituminous coal; and there is anthracite coal. These are distinguished by their appearance, and they may be known at a glance by their colour, lustre, and cleavage. A bituminous coal, such as cannel, contains a deal of tarry matter and other ingredients, which are technically known as hydrocarbon. Such coal makes much smoke and more ash than other kinds of coal. It demands a special degree of skill to work it, and a large grate, over which to mix plenty of air with it. A slightly bituminous coal, such as Welsh or anthracitic coal, contains very little tarry matter and makes but little ash. Comparatively speaking, it is smokeless, although not literally so, but what smoke it emits is clean. Under the influence of heat, the coal assumes an appearance which reminds one of a head of cauliflower. Welsh coal contains a very small amount of hydrocarbons, and is therefore the best of steam coals. Semi-bituminous coal, such as Derbyshire coal, contains hydrocarbons to a considerable degree, but not to such an extent as to require more than ordinary attention.

Those who use steam power at a distance from the pit-mouth should use Welsh coal and semi-bituminous

coal in equal proportion, which should be mixed prior to being used.

With an entirely smokeless coal, combustion takes place with little or no flame, and the heat from the incandescent mass on the bars is rapidly absorbed by the water in the vicinity of the furnace.

When a mixture of coal is used, there is a development of gas and flame which the current of the draught induces to flash along the tubes and flues, where there is an abundance of heating surface ready to take up the heat. At any rate, a judicious mixture has a tendency to insure a more equal temperature of heat throughout the boiler. This is a cardinal point.

From the above remarks it may be inferred that there are four classes of coals, regulated by chemical composition, and that those which contain the most tarry matter, that is to say, having a large per-centage of constituent hydrocarbons, make the most smoke.

What is smoke?—When we see a beautifully clean lamp-globe soiled by a black cloud, we instantly turn down the wick a little. The cloud of black smoke, either issuing from a globe or a chimney, is the result of precisely the same causes. If the lamp is well supplied with oil and cotton, and there is abundance of flame and smoke, the smoke is caused by an insufficiency of air to effect perfect combustion of the combustible matter, oil.

It may be asked, why does the lowering of the lamp-wick slightly make all the difference between a black cloud and a white light? The answer is, the relative proportions of combustibles and air are then exactly adjusted.

CHAPTER XIII.

MANAGEMENT OF THE FEED-WATER AND OF BOILER FEEDERS.

THE maintenance of steam depends to a considerable extent upon the manner in which the boiler is fed with water. The aim should be, as far as possible, to regulate the supply to the demand—just sufficient to keep the water at one level in the gauge-glass. By doing so, an even temperature may be maintained within the boiler, which may be the means of prolonging its life, as an irregular temperature shortens it. There are various opinions as to the benefits derived by heating the feed-water by the exhaust steam; but opinions are unanimous that the feed-water should be heated before it enters into the boiler. At the best of times feed-water can only be heated to 212°, and even at that temperature there is a considerable difference between the temperature of the feed-water and that of the boiler.

The objections advanced against heating feed-water by injecting the exhaust-steam into it, are founded upon the fact of grease having been found upon the surface of a burnt boiler-plate. To the deposition of such grease, in conjunction with carbonate of lime, the burning of boilers is attributed. There can be no

question that a thin film of grease combining with carbonate of lime, a floury deposit, prevents the contact of water with the hot plate, just as surely as grease prevents a revolving axle from touching the journal or brass. Besides, the presence of grease increases the tendency of many boilers to prime, and hinders the circulation of the water, by forming, with mud and other matters, an insoluble soap, and thus causes no end of trouble. It searches out every particle of carbonate of lime, priming is set going, and out goes the cylinder end before the engineman is aware of it. The danger of using grease need not be dwelt upon, but the danger lies in the abuse of grease. When used in such infinitesimal quantities as are to be found in the feed-water when heated by the injection of a portion of the exhaust steam, it sometimes only has the effect of detaching scale from the plates.

There is an objection to heating the feed-water, either by injection or by passing it through a coil of pipes in water, in the precipitation of lime salts in the feed-pipes, which become choked. The pump in consequence becomes disabled. The feed-water, containing bicarbonate of lime in solution when cold, precipitates when heated the greater portion of the lime salts. The lime is left behind, or is left spread over the interior surface of the supply pipes between the cistern and the boiler. We must be prepared to attack and remove the lime before any disadvantage or inconvenience is suffered.

In practice, there are almost as many points for introducing the feed as there are boilers. In Cornish and Lancashire boilers, the feed is delivered very frequently near the bottom of the boiler, which is

the coolest part of the boiler. It was for a long time maintained that such was the proper place for the admission of the feed, to obtain the maximum evaporative efficiency. It was this consideration by which the earlier locomotive builders were led to introduce the feed by the side of the fire-box, even when cold; but, when the feed-water is not heated, such practice would never be tolerated in these enlightened days. Many boilers are fed at a level just below the fire-line, and the water, instead of being concentrated at a single point, is received from the feed-pipe by a perforated pipe or trough inside the boiler, by which it is distributed in the best manner so as to avoid extremes and to conduce to steady steaming. When the feed-water is naturally bad, containing impurities of a mechanical or a chemical nature, the influence of the impurities may, by continual watching, be detected in the boiler, steam-pipe, and cylinder. Should the water prove refractory in the boiler, and have a deteriorating action, the only remedy is to dilute it with the condensed water from the engine as much as possible, and by means of the scum-cock to clear the surface of the water in the boiler several times a day.

Now, as regards the saving of fuel by heating the feed-water,* if we take a boiler working to a pressure of 40 lbs. per square inch above the atmosphere, with feed-water at 60°—the normal temperature—the total heat absorbed in the formation of steam of 25 lbs. effective pressure from cold water would be (1201·0° — 60°) = 1141·0°. But, if the feed-water be heated to and supplied at 212°, the heat absorbed would amount

* A Treatise on Steam Boilers, by Robert Wilson. Fifth Edition, 1879.— Crosby Lockwood & Co.

only to $(1201° - 212) = 989·0°$, which shows a gain of 152°, or 12½ per cent.

Although a large measure of heat is economised and returned to a boiler in the course of a day by heating the feed-water, it must not be considered to be the sole element of good thereby effected. There are others, such as a diminution of intermittent expansion and contraction, purification of water, and constancy in steaming.

Feeders.—The necessity of great attention being paid to the perfection in principle, manufacture, and action of the pump for boiler feeding is obvious. The sinking of the water below its proper level in the boiler has not only caused many explosions, but it has also produced a considerable amount of inconvenience in a factory by causing the fires to be drawn, through a defective pump. It is not an uncommon occurrence for a lot of men who are working machines to be thrown idle for an hour because the engineman could not get any water into the boiler. In modern times, with so many feeders, such an accident should not happen. But then it does happen, and nine times out of ten it happens with the old apparatus—a pump. We may notice some of its faults.

The plunger, or piston, the valves, and the barrel may be faulty to begin with. The plunger may have been badly turned, and may not be truly cylindrical; the stuffing-boxes too large, they may be badly packed, or the pump-barrel may have been carelessly and unequally bored. The piston-pump is sometimes badly leathered, allowing air to enter, which destroys its efficiency.

The valves may be faulty in consequence of not

having been made of hard metal; they may be too small for passing hot water, and may have too much lift; they may be liable to wedge themselves and stick fast; they may have been formed with too much taper; the surface of contact may be too broad or too narrow; the valves may not be provided with proper means of access for repair or removal. These defects require to be constantly watched. There are a few other occasional deficiencies. Sometimes the suction-pipe is so placed that it may fail to act when the water is low in the well, and half a day may be lost in examining valves, &c. By the time these have been taken out and cleaned, and the obnoxious morsel of dirt found in the pump, the water in the well has risen, and when the fires are relighted and the engine set to work, the necessary quantity of water has been collected.

Again: when the water is known to be full of foreign matter—as straw, chips, sand, sawdust—it often happens that the engine attendant does not take any precaution to prevent its entering the pump with the water by the intervention of a strainer. In districts where the water requires to be strained, the strainer should not be fixed close to the suction-pipe; as this would interfere with its action, but it should be placed at a distance in a convenient position to form a division in the cistern or reservoir from which the pump is supplied, so that the impurities may be easily collected as required, and removed from the water.

The division may be made of fine wire, and so arranged as to divide the water into two unequal parts, into the smaller of which the water supply is delivered, and from the larger of which the pump is

supplied. The cistern must be covered in to keep the water free from objects that might be thrown into it.

The most ancient pump with which we are acquainted is that of *Ctesibus*. It was a force-pump which was used before the nature of a vacuum was understood, and therefore was in existence before the suction-pump.

A force-pump acts by pressure; a suction-pump by exhaustion.

In the ancient force-pump the water was brought into the body of the pump by gravitation, and it was forced out by a piston-plunger to any suitable elevation. The only valve was a stop or foot-valve to prevent the water, on the descent of the piston, from returning to the source of the supply. The water, therefore, found an exit in some other direction. The quantity of water obtained at each stroke would be equal to a column having the diameter of the piston and length of its stroke. This was a very simple pump; but when the water was required to be lifted above the pump, say through a vertical pipe, it is clear that on the piston making the out-door stroke, water would follow it and occupy the vacant space in the barrel more or less. If sufficient water followed the piston to completely fill the space left by it, then no useful work could have been performed, no water delivered. If the space in the barrel was half filled by returning water, then a useful effect equal to half the whole work done would have been secured, so that for a long time the lift of the water above the pump could have been only so far attained as the cubical capacity of the delivery-pipe was less than the cubical capacity the barrel of the pump. Following this imperfect

condition of things, new wants required new improvements, and the next thing was the insertion of a head-valve, above the pump, in the delivery-pipe, so that the water was prevented from returning on the piston. The valve was made to open from the pump, and with a foot-valve and a head-valve, the arrangement was complete as for a force-pump. At this early period atmospheric pressure was not thought of for forcing water into a vacuum.

When the pump was put to work, water very soon began to flow, and the pump was said to lift the water, though why it should be able to do such a thing no one could explain. When the water is below the pump, the air is pumped off the top of the water, and is forced like water into the delivery-pipe; then the water rises into the pump. We will examine into the cause of the water rising in this manner, as hundreds of people have still a belief that the pump lifts it. The ancients could not explain it otherwise than by declaring that the cause was that "nature abhorred a vacuum."

For the real explanation we are indebted to Galileo and his pupil Torricelli.

The former philosopher taught that air had weight; the latter showed, by incontrovertible experiment, that the rise of fluids in pumps was owing to the pressure which his master was expounding to the brother philosophers of his day. These truths became the chief scientific questions of the hour, and they are at this day of great practical interest in the art of engineering.

Torricelli constructed a barometer, and he demonstrated that the pressure of the air on the surface of the water would raise the water from the well to the

pump-valve, provided that the distance did not exceed 34 feet, and that the air was all pumped out of the suction-pipe. The weight of the atmosphere on the ground is due to the superincumbent mass of air above, which is estimated by some to be not less than fifty miles high. This mass weighs 14·7 lbs., or nearly 15 lbs. per square inch of horizontal surface at the level of the sea, and the air, in virtue of its elasticity, exerts the same pressure in all directions on bodies which are exposed to it. Having made this explanation, we may now proceed to consider the action of the *suction*-pump, or the pump which is commonly stated to lift water.

A common back-door pump is one of this class—suction—and as every one is familiar with its effects, we may safely select it to assist us in our endeavours to inform young enginemen why it is called a *lift-pump*. The common suction-pipe is fitted with what is called a bucket, being, in fact, a piston with a *valve* fitted to it opening from the water, which may be 20 feet below it. Below this valve there is another *valve*, opening from the water like the bucket-valve. When the pump-handle is lifted high, the bucket is *lowered* so that it almost then touches the lower valve, and when the handle is lowered, the bucket is lifted and it is placed at some distance from the lower valve, sometimes not more than six inches. But, as already stated, the water may be 20 feet lower, or more. The *limit* with a good pump is 30 feet. When the pump is not in action it is full of air in the interior of the *barrel*, and down the suction-pipe. There is air also on the surface of the water in the well. The *pressure of the* air within and that of the air without the pump

balance each other. Now, suppose we raise the pump-handle and bring the valves together, and then commence to pump. Upon elevating or raising the bucket, the air above it keeps the valve down, because it opens only from the inside; and, therefore, when the stroke is completed, the space between the valves is empty, being a vacuum, and it would remain so were it not that the air underneath the bottom valve gently insinuates itself past the valve and takes possession of the vacant space. As soon as the bucket is lowered, the air immediately under it is compressed. The bottom valve is thus closed, and the bucket-valve is opened, when the air escapes through the spout. Another up-stroke is made, in consequence of which the upper valve is closed, and another vacancy is formed. Air again enters this place, and it is pumped out as before.

It follows, then, that at every stroke the air within the pump is rarefied and its elasticity is diminished, and its presence is gradually got rid of inside the pump from the surface of the water in the suction-pipe to the underside of the bucket-valve. Thus far the *pump* has acted simply as an air-pump.

Now, having exhausted or sucked all the air out, there is, as between the interior and the exterior of the pump, unbalanced atmospheric pressure, and by the preponderating pressure of the air in the well outside the pump, the water is forced up the suction-pipe and through the bottom valve into the body of the pump, occupying the space between the two valves. The pump is then said to be charged. When the water is pressed by the lowering of the bucket there are two effects—one is to close the bottom valve, the other is

to open the top one, through which the water passes as the bucket is lowered; and when the two valves are brought close together, all the water is obviously now above the bucket-valve. The instant that we attempt to lift the bucket, the weight of the water closes its valve; and, therefore, by raising the bucket the water is lifted to the spout, through which it is discharged. Thus the pump is said to be a lift-pump. As the bucket is lifted, with its weight of water above, water is at the same time entering into the pump under the bucket to occupy the vacant space formed by it in its ascent.

This pump, the common suction-pump, operates by the formation of a vacuum within the working barrel; and it is incapable of raising water from a *level more than* 34 feet deep. But water may be delivered at great distances by employing valves and air-vessels, as in the case of waterworks, so that a pump may be so constructed as to draw the water by *suction*, and *force* it to any required height. Such is the principle of the pump, worked either by manual or mechanical power. There are bucket-pumps, piston-pumps, and plunger-pumps.

A *bucket-pump* is a single-acting pump: the *bucket* being a piston with a valve fitted to it in the centre which closes on the up-stroke and opens on *the down-stroke*, lifting a quantity of water equal to only the capacity of the pump in one revolution of *the engine.* It is fitted with foot and head valves. Such a pump we have just considered.

The *piston-pump* is either single-acting or double-acting. It is fitted with suction-valves and *delivery-valves* in juxtaposition with the working barrel.

The *plunger air-pump* is a double-acting pump, arranged like the bucket air-pump, except that there are no head-valves, and that the bucket-rod is fitted with a large plunger. The effect of this is that, whereas the ordinary bucket air-pump discharges only with the up-stroke, the plunger air-pump, owing to the displacement caused by the bulk of the plunger, discharges on the down-stroke as well.

Injector.—Since the injector was invented by Giffard, and brought into practice, it has generally done its work satisfactorily, and at a small cost for feeding the boiler.

It was a great novelty when first introduced, and it very soon became a favourite with railway enginemen; and the cause is not far to seek. It could be used either when the engine was disabled, or when the train was put into a siding. It was a friend in need under trying circumstances, such as are common upon a railway, when a pump could not afford the same help. I refer to train-engines that are delayed upon the main line or on branch lines by an accident in front. It used to be a very common practice under such circumstances to draw the fire in order to save the boiler. To do so in these days would be to degenerate to the old style. At a small expense, an injector can be provided and attached to every engine, and in every engine-house.

Probably no invention was ever placed in the hands of enginemen that they knew so little about, and which they were yet able to work efficiently. Not one engineman in five hundred can explain the action by which the instrument delivers water into the same boiler as that from which it is supplied with steam.

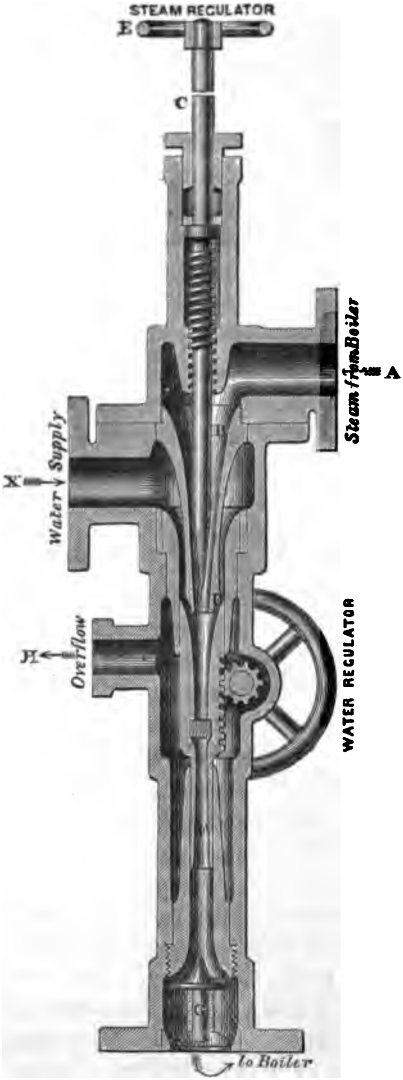


Fig. 19.—Giffard's Injector.

It has formed the chief topic of warm discussions over many a flowing tankard; it has led to blows; it has divided the best of mates, for it is a "nut" that few, very few, in the engine-house, have the fortune to be able to crack.

Steam is admitted into the injector through a cock on the boiler, to obtain steam free from water. When the cock is open, steam can enter the injector through A, and occupy B surrounding the spindle C. The spindle is finished conically at its lower end, and forms a valve which may be closed steam-tight at D, controlling the egress of the steam into the lower por-

tion of the injector. When the wheel E, on the end of the spindle C, is moved to raise the spindle, steam rushes through D, past the mouth of the inlet-pipe X leading from the water-supply. The current of steam by the suctional action draws the air out of the pipe leading to the water, and relieving it of atmospheric-pressure, a vacuum is formed in the pipe between the injector and the water, by virtue of which it ascends and enters the injector.

The action of the injector is entirely due to the *concentration* of the steam issuing from a cone, A, Fig. 20, which must be taken as representing the *power* of the instrument. Here the steam is condensed, and is concentrated by means of the water flowing in at the combining cone B. The united streams of water and steam are passed into the receiving cone D, where the *resistance* to the entry of the water into the boiler is experienced. The sectional areas of the cones differ, as a matter of course, and the areas of A and D, at their smallest diameters, are about as 2·0106 is to 0·7854.

The injector takes advantage of the superior velocity with which steam issues from a boiler as compared with water, and may be regarded as an instrument *for producing a combined jet of steam and water, flowing through a nozzle at a higher velocity than that at which a corresponding stream of water would issue from the same boiler that supplies the steam.*

When the water comes within the scope of the current of steam, it is carried along by the concentrated steam acting upon it. The water, which is incompressible, is projected forward into the delivery-pipe, and thence into the boiler by the impulsive force of the steam, the velocity of the steam being due to its elastic

pressure. The expansive force of gunpowder is confined by the shot to the powder-chamber, where the force is concentrated that ultimately sends the ball hissing through the air. So with the action of injectors, the force is concentrated by the water at the cone, and instead of there being one effect as with a charge of powder for one shot, the injector, whilst steam is on, is *always* charged, and there is a *continuous* discharge of water.

The reason why an injector will not work with feed water of a greater temperature than from 130° to 150° is that it requires so large a quantity of water to condense and concentrate the current of steam from the cone A, that the speed of the water cannot be sufficiently accelerated by the force of the steam to overcome the virtual speed of a corresponding stream of water issuing from the boiler.

The ratio of the quantity of water entering the boiler is to that of the steam used, as about 18 to 1; that is to say, that for one pound of steam issuing from the boiler, eighteen pounds of water are forced into the boiler. The temperature of the water is raised nearly 100° Fahr. during its passage into the boiler when the pressure is about 70 lbs. per square inch.

From this explanation an engineman should be enabled to form at any time an opinion respecting an injector that is defective in its working.

We will assume that, after an injector has been at work all right for a short time, it throws off—stops working.

There are three causes by which a stoppage is produced:—First, the injector will go off when the water exceeds a certain heat; but it may be argued that as the injector took the water at first, why not continue

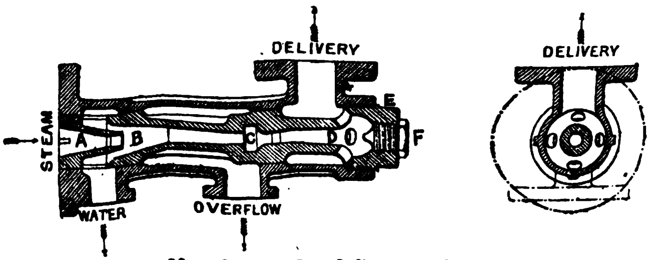
doing so? Because the inj cool when first set on, and greater or less extent to cool heated. Secondly, the water had the same temperature hotter portion entered the inj steam and concentrate it. throw off when the volume o boiler is insufficient to give t water, so as to overcome the water and steam within the bo be said: But the steam work Yes; but the water which has was comparatively cold, and thi rature of the steam, and conse the cone A, whilst the volume same as when the injector was f condensed *entirely*, and there given to the water.

We never see an invention, capable of being improved upo the road which reaches to the g

Giffard's injector is very sensit is very much boxed-up, and whe and "off" it wastes much water pipe at each operation.

The advantages claimed for t sham injector, Figs. 20, over the first and foremost, that it will temperature does not exceed attended, as every engineman advantages. There are occasion been stopped, on which the boile

steam, and when it blows off at the safety-valves; not only making an unbearable row, but wasting steam. If this disagreeable din and waste can be avoided by blowing back surplus steam into the tank, without annulling the power of an injector, it must, to say the least, be of great benefit. Such is the Gresham injector, of which the next recommendation is, secondly, that it readily adapts itself, without adjustment, to the varying pressure of steam under which the injector has to work. The advantage of this is like that of a pump which can be regulated so as just to maintain the water



Figs. 20.—Sheward and Gresham Injector.

in the boiler at the best working level; but, very unlike the pump, the water through the injector enters the boiler in a continuous stream, in place of by such intermittent action as is common to pumps. In fact, the injector, compared with a pump, may be considered as a continuous ram with a continuous piston. Thirdly, the advantage of being able to withdraw the working-parts of injectors may have struck many enginemen who have had experience of them. In the injector now under notice, the *whole* of the internal parts can be withdrawn from the external case without breaking any pipe-joints, by means of the nut E, and the interior,

which sometimes gets choked or furred up, can cleaned and the instrument returned to the case w the steam up.

Some inquisitive spirits will want to know why t injector takes *hot* water. The explanation is that it due to the good proportions of the various cones, a to the fact of their being fixed as much below the le of the supply-water as possible.

Instructions for working the Gresham Injector.—Open the water-supply *slightly* by the cock on wa supply pipe, when, with a non-lifting injector, the w will enter it.

2nd. Open the cock on steam-supply pipe slig until water issues freely from the overflow-pipe; open the cock full. If water continues to issue the overflow-pipe, regulate the water supply until overflow ceases.

The quantity of feed-water supplied to the b through the injector may be increased or decreased pleasure by opening or closing the regulation-cocks.

The Hancock Inspirator.—This instrument, American invention, constitutes a still further advan upon the Giffard injector. It is a double apparat Fig. 21, one-half of which is a lifter, consisting lifting jet and a lifting nozzle; and the other half forcer, consisting of a forcing jet and a forcing noz or injector; the lifter drawing the water and deliveri it to the forcer, which delivers it to the boiler. though both the lifting and the force-nozzles are fix their proportion, one to the other, is such that inspirator does not require any adjustment for chan in steam-pressure or in water-supply, the waste-va being kept closed while the instrument is in operati

except at the time of starting. By means of the inspirator, water can be lifted 25 feet, and delivered into

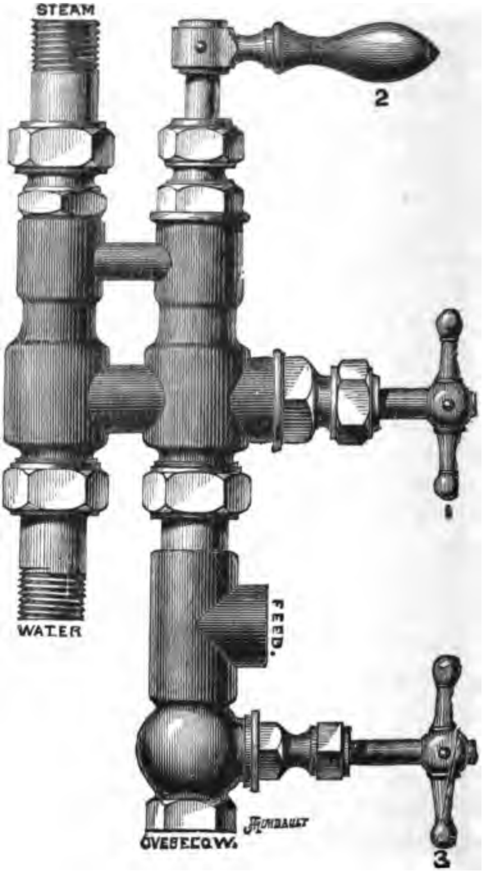


Fig. 21.—Hancock Inspirator. Stationary Bo lers.

a tank or a boiler, as required, with a steam-pressure of 30 lbs. per square inch. The temperature of the

water may be as high as from 90° to 100° Fahr. for a lift of 25 feet; or it may be as high as 125° Fahr.

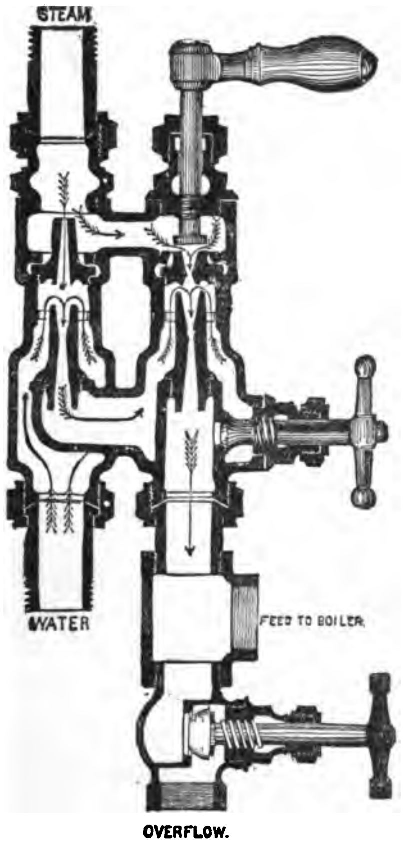


Fig. 22.—Hancock Inspirator. Vertical Section.

for a lift of 3 or 4 feet. The inspirator for stationary boilers is shown in section, Fig. 22. By means of the uppermost valve, the admission of steam to the

forcing jet is controlled; by the middle valve is regulated the flow of the water delivered by the lifting jet

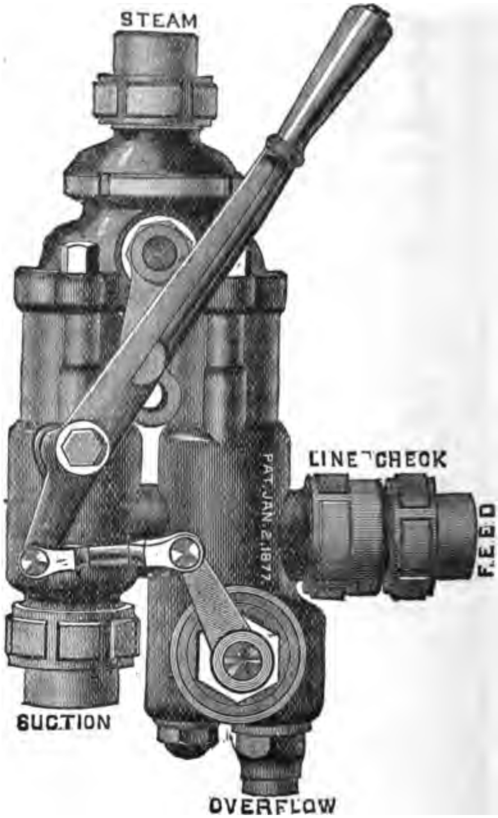


Fig. 23.—Hancock Inspirator for Locomotives.

into the forcing tube; by the lowermost valve the overflow is opened and closed.

The locomotive inspirator, shown in Fig. 23,

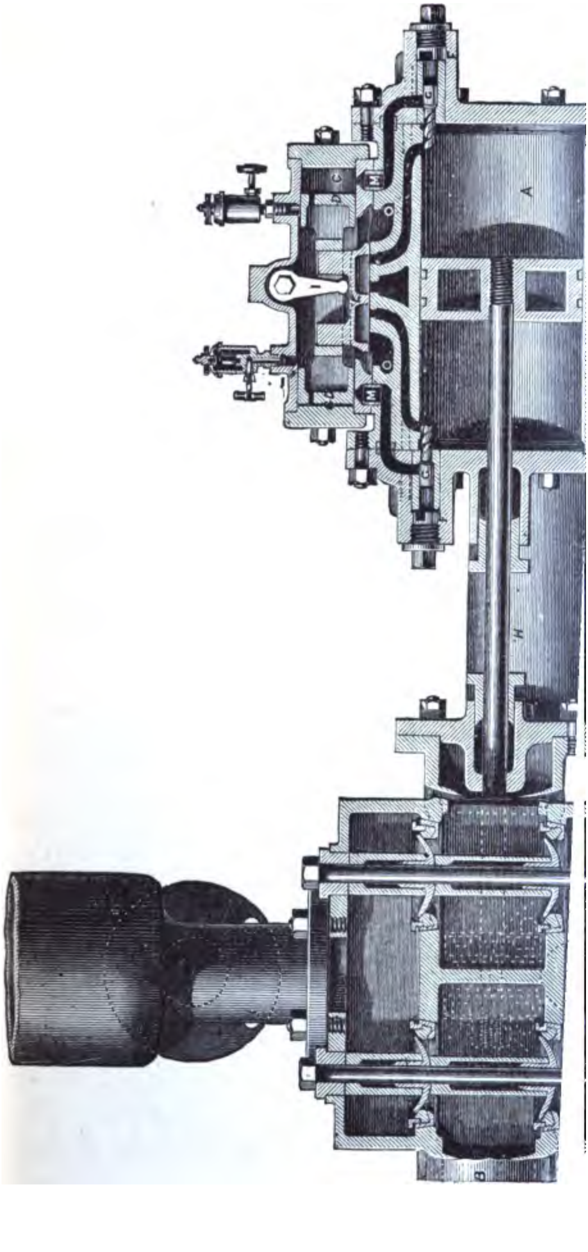
deserves a word of notice. It is the same in principle as that of the stationary inspirator; but the arrangement is such, that all the operations of starting and stopping can be performed by the movement of a single lever, and the instrument is self-contained. By a slight movement of the starting lever, steam is admitted to the lifting jet. When water issues from the overflow, by a further movement of the starting lever one of the valves is closed—thus turning the supply water through the force-nozzle—steam is admitted to the forcing-jet and the waste-valve is closed, thus starting the instrument.

An elaborate series of trials of the Hancock inspirator was conducted at Boston, U.S., by Mr. R. H. Buel According to a table of some of the results of these trials with No. 30 instrument, for stationary boilers, in which the smallest diameter of the force-nozzle was 0.30 inch, or nearly $\frac{5}{16}$ inch, when the lift was from 2 to 3 feet, and the temperature of the water supplied was 70° Fahr., whilst the pressure of steam supplied to the inspirator, as well as the pressure against which water was delivered, varied from 15 lbs. to 150 lbs. per square inch, the maximum rate of delivery varied from 100 cubic feet to 144½ cubic feet of water per hour; and the minimum rate of delivery, when the steam-valve was wide open, and the supply was throttled, was from 60½ cubic feet to 78 cubic feet, with steam of 140 lbs. pressure. The temperature of the water at maximum delivery varied from 103° to 191° Fahr.; at minimum delivery, when the steam-valve was opened wide, and the supply throttled, the temperature varied from 184° to 230° Fahr., under pressures of from 40 lbs. to 150 lbs. per square inch; and, at minimum

delivery, when the steam-valve was throttled, and the supply-valve was opened wide, the temperature varied from 134° to 168° Fahr., under pressures varying from 80 lbs. to 150 lbs. per square inch. The vacuum in the supply-pipe varied from 4 inches to 23½ inches of mercury, between the extreme pressures of from 15 lbs. to 150 lbs. The lowest pressure of steam with which the inspirator delivered water against these extreme pressures, varied from 11 lbs. to 90 lbs. per square inch.

From the results of another series of experiments, it appears that with a lift of 2 feet, for pressures of from 15 lbs. to 150 lbs., the highest admissible temperature of supply water varied from 130° to 144° Fahr., and the temperatures of the delivered water varied from 170° to 280° Fahr. More recently, inspirators have been constructed capable of supplying locomotive boilers with water drawn at 150° Fahr. of temperature.

Tangye's Special Steam-pump, with Key.—But few modern inventions have, in the course of a few years, received such patronage as the Special Pump illustrated in longitudinal section, Fig. 24. The great advantage of this pump is that it is double-acting. After it is started, it catches up the water and delivers it into a boiler in a constant stream, and not in intermittent quantities like the ordinary engine-pump. It is capable of keeping up a constant and steady flow of water, and it adjusts itself to the fluctuations in the pressure of the steam. It can be regulated to supply a boiler with water at the same rate at which the water is evaporated and consumed. The motion is known as a "tappet" motion; that is to say, it is one in which



the movements of the valve are regulated by its coming into contact with adjustable lugs, with cambs, and with a reversing-valve.

The key to the pump will enable those who have not yet had experience of it to form an acquaintance with the pump. The steam-cylinder and the pump-cylinder, A and B, are placed in a line with each other, and they are connected by distance-pieces H, the end-flanges of which form the covers for the two cylinders. The steam-cylinder A is made with a double set of steam-passages, one pair of these passages leading from the slide-valve face to the ends of the cylinder in the usual way, and the other pair extending from near the ends of the steam-chest to the inner ends of small cylindrical chambers formed one on each cylinder cover, F F. Each of these chambers is fitted with a reversing-valve G G, which closes an opening in the cylinder-cover: these being—except when moved by the piston—kept against their seats by the pressure of steam on their backs, the outer ends of the valve-chambers being placed in free communication with the steam by small passages.

The slide-valve E covers the exhaust-port and one pair of steam-ports, and it is made of the section shown, so that when it is removed to the right, steam is admitted into the right-hand port and *vice-versâ*. The valve is shown in the engraving in the position which it occupies when steam is being admitted into the left-hand port; the other port being placed in communication with the exhaust. On the back of the valve are a pair of lugs fitted between two collars, formed on a spindle connecting a pair of plungers, D, D, which work in the cylindrical portions forming the ends of the

valve-chest, C C, and into which the second pair of steam-ports, M M, open.

The plungers, D D, are for the purpose of shifting the slide-valve; and they are made to work comparatively free, so that sufficient steam will pass them to form a cushion at either end alternately.

When the pump is at work, the finger I of the starting-lever remains stationary, as the valve does not move far enough to touch it.

The action of the apparatus is very simple. Supposing all the parts to be in the position shown in Fig. 24, the piston will, when steam is turned on, move from left to right. On arriving at the end of its stroke, it will open the reversing-valve G in the right-hand cylinder-cover, thus placing the second right-hand steam-passage in communication with the right-hand end of the cylinder; and consequently, owing to the position of the main-valve, in communication with the exhaust. This being the case, the pressure is removed from the back of the right-hand plunger D, connected with the main-valve, and the pressure of the steam on the inner-side of the plunger then forces the latter to the right, the slide-valve being of course carried with it.

By this movement, steam is admitted to the right-hand end of the cylinder, and the left-hand end is placed in communication with the exhaust. The piston then performs its stroke from right to left, when the operations already described are repeated at the other end of the cylinder.

The action of the valve is not the same in all the Tangye pumps. The section, Fig. 25, exhibits an improved form of reversing valve, E, K. It will be seen that these valves are placed in the passage of the

steam cylinder instead of in the covers, and that they work in a direction perpendicular to that of the piston; the object being to render the valves under all circumstances absolutely certain in action. The piston, on arriving at the end of its stroke, and its edge being slightly bevelled, will lift the improved reversing valve off its seat. This removes the pressure from the back

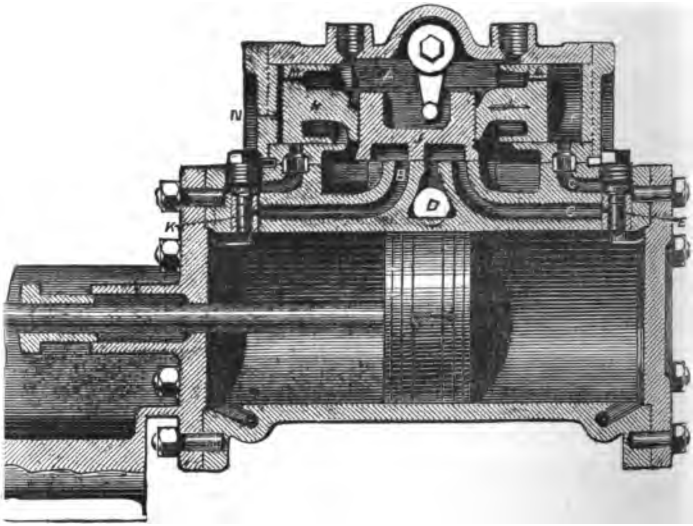


Fig. 25.—Tangye's Special Steam-Pump.

of the right-hand plunger connected with the main-valve, and the pressure of the steam on the inner side of the plunger then forces the latter to the right, the slide-valve being of course carried with it. By this movement steam is admitted on the right-hand end of the cylinder, and the left-hand end is placed in communication with the exhaust. The piston then per-

forms its stroke from right to left, when the op described are repeated on the other side or end

Starting the Pump.—Before starting a pump, the cylinder should be warmed by steam through it and out of it by way of th water cock. The lever I, Fig. 24, then may be w hand backwards and forwards a few times, no full stroke, but for a short portion of the stro so that all the water may be blown out of the I and that a regular temperature may be throughout the working parts. Should the I any time during ordinary working, instead of a full stroke, travel to and fro at one en cylinder, the plug F at the opposite enc cylinder should be unscrewed and the pis blown out by steam, cleaned and returned to A little grit will sometimes prevent its wor perly. For lubrication, suet should be used, is better and more genuine than tallow or much more economical in cost than either of

Delivery of Supply.—To ascertain the q water that a pump will deliver, it is necessa late the solid or cubical contents of that] barrel in which the vacuum is produced an it to some standard measure, and to multi the number of strokes made in a given t pump-ram is nine inches in diameter, an effective stroke of 18 inches, its performa found either for each stroke or for a numbe The pump illustrated above has a capac cubic inches, which, divided by $277\frac{1}{4}$ c the volume of an imperial gallon = 4 that is, supposing the ram to be at th

outdoor stroke and the pump full of water, it would displace 4·13 gallons by making the indoor stroke. Therefore it is clear that at the rate of 10 strokes a minute $41\frac{1}{4}$ gallons would be displaced or pumped out per minute; and at the rate of 100 strokes a minute, 413 gallons will be displaced, or 60 times 100 strokes; for the work of one hour $= 413 \times 60 = 24{,}780$ gallons. As a gallon of water weighs 10 lbs. the total weight delivered in the hour would amount to $(24{,}780 \times 10 =)$ 247,800 lbs.

CHAPTER XIV.

CAUSES OF FAILURES.

It is not an unusual occurrence for a stationary engine to break down by more causes than one, and by causes unknown to enginemen.

One man may have a list of failures, an extensive list, which he might show to another man, in the belief that it exhibited rather extensive experience in break-downs, and yet he may find himself face to face with facts and incidents quite beyond the range of his experience. It is highly commendable to find out the cause of a success, but, it is only by knowing *how* and *where* engines have failed, that a man can be made a complete engineman.

As things are at the present time, when almost any man who has the slightest pretence to an acquaintance with engines can procure a berth to look after an engine, it is our duty to try and meet the evil. That there are men in charge of engines who know nothing excepting shovelling coal, is a fact; and they are not to blame for getting into the engine-house to change the shovel for the "STOP" and "STARTING" lever. That being a fact, for which at present there is no remedy, the following list of failures and the causes may be of value to those who feel their need of information. A man is

before us who is well aware that hot water, if poured into a glass, will crack it, spoil it, break it, and still he turns steam, which is hotter than the water in a kettle, into a cold cylinder and cracks that; which may cost two or three hunded pounds to put right again. Here is a man who knows that if the water in the kitchen pipe is turned off suddenly, he will have in all probability to pay the plumber to patch the bursted water-pipe, and still he will go to his engine and shut off a stop-valve suddenly, and is surprised that the steam-pipes crack and the boilers burst.

We will give some cases which have come before us.

An engineman broke in halves the beam of an engine of 80 horse-power, by allowing the injection-water in the condenser to augment until it entered the cylinder. The water, being incompressible, resisted the "down" stroke of the piston, the momentum of the fly-wheel resisted the "up" tendency of the water, consequently the weakest point between the crank-shaft and the condenser was found in the centre of the beam, where it parted, and it came down with a great crash to the floor. This accident was caused soon after starting by not so regulating the supply of water to the condenser that the air-pump could discharge it into the hot-well.

An engineman broke a beam in halves, not noticing that the foot-valve of the condenser was out of order, which disabled the pump.

An engineman broke a beam by allowing blocks of wood to lie about the engine-house, until they were accidentally knocked into the pit of the fly-wheel, where they glided between the rim of the wheel and the masonry, forming a kind of break-block against the steam on the piston.

An engineman blew an excessive quantity of steam through the cylinder-jacket, and so heated the water in the condenser, that it caused the air-pump bucket to expand, and created sufficient friction to bend the pump-rod.

An engineman, by not blowing sufficient steam through the jacket, split the cylinder by admitting steam into it before its temperature had been sufficiently raised.

An engineman started his engine without examining it properly, causing some waste to be the means of breaking a pair of geared wheels, which incurred an enormous amount of delay and expense to the proprietor.

An engineman, getting the chill off a slide-bar and slide-block, caused them to expand and attempt to grip. The slide-bar seized down upon the block, and the block seized up to the slide-bar. After he had oiled it, it did not appear to improve, the two faces fitting so closely as to exclude even a film of oil; and the engine was compelled to run at half speed for a time. This mishap was caused through the refuse in the oil blocking up the pores in the worsted trimming, and thus preventing the oil from lubricating the bearing.

An engineman allowed the lid of an oil-box to fit air-tight, and consequently the trimming would not act properly. He retrimmed it and still the bearing would get hot; he altered the trimmings several times, but his efforts were of no avail. The mill, however, had to be kept going to finish some important work, and by the end of the week the journal and the brass were considerably cut. The engine was of course

delivered over to the engine-maker for repairs. It may be asked how it was that the lid became tight so suddenly. We have simply to refer to the fall of the lid of the box on to the edge every day, by which the inequalities on the two faces were smoothed away, in time making a perfect air-tight joint, excluding the air from forcing the oil down the worsted pores, and therefore if a box was full of oil and the lid was air-tight the journal would run without obtaining any oil. Scores of journals run hot through the boxes being air-tight, and the remedy is seen too frequently applied in the wrong place, namely, by filing a notch in the box edge. Sometimes this is made sufficiently deep to make it impossible for the fall of the lid to obliterate it; but even then there is danger of its becoming air-tight, especially when tallow is mixed with oil. The proper way is to admit the air through the centre of the cover by a hole, in which a small piece of sponge should be placed to prevent the dust of the engine-house entering the box and clogging up the siphon-cup.

An engineman took his feed-water from a brook, and allowed some chips to enter the engine-well, which were drawn up the suction-pipe into the pump, and, getting under the clack, disabled it. Time was lost in attempting to get the clacks to fall by pouring cold water upon the pump to condense the steam under the valve. Sometimes valves are held up by the steam in this manner when they are seated too high and require lowering. The boiler, becoming short of water, the engine had to stop, and the top clack being up, the second clack could not be examined, so that the steam had to be blown off from the boiler and the works stopped, by

the absence of a strainer in front of the well, and
want of a head that could see the chips floating in
brook and the same chips underneath the clacks.

An engineman was short of steam, and was no
to pump a sufficient supply of water into a large
Complaints were made, and he had the affair in h
hands. But the pumping did not improve, an
man stated it was all the fault of the boiler, th
the boiler was inspected it was found that the
work all round the front was broken, and the
was drawing air there. So soon as this was
up and made air-tight, the draught in the chimney
restored. The fire depends upon the chimney
and not upon air that can steal into the flues
dilapidated mortar and masonry.

An engineman became short of steam through
ing the flues to be choked up with soot.

In consequence of an engineman not looking after
the cleaning of his boiler it was made up with stone
deposit.

In consequence of an engineman not making an exami-
nation before making a fire under a boiler, he burned
it, by its being short of water. The boiler had been
filled up overnight, but it had sprung a leak, no doubt
through the sudden contraction of the plates at the
time or after the fire had been drawn, and through the
fire-door being open and the damper up.

An engineman washed a boiler out and filled it with
water again, and the next morning he made the fire up
in the usual way. After a little while, when he began
to think the steam should appear, he perceived some-
thing smoking on the top of the boiler, which he found
to be an old bag, and directly afterwards he found the

flue red-hot. Where could the water have gone? It went out through the blow-off cock, which was not shut close. All blow-off cocks should be carefully watched, because they may sell a man at any time when he least expects it, through ordinary wear and tear.

An engineman was blowing steam out of two boilers into a third, in order to have the third in working order quickly. When he considered that there was sufficient in the third boiler, he shut the communicating stop-valve suddenly, and burst the other two. When steam is stopped in its motion, it will of course rebound like anything else—like a stone, if you will, or a shot.

The force of elasticity produces motion in the steam, and it has a tendency to continue that motion until acted upon by some extraneous force. As soon as the stop-valve was shut in the instance referred to, the current of steam towards the valve was momentarily accumulated upon the valve, and the pressure correspondingly increased. The result was that the current of steam reacted into the boiler, bringing to bear sufficient power and pressure upon the water to burst the boiler.

An engineman, by opening a stop-valve suddenly, split a large steam-pipe, and consequently disabled the engine for two days, there being no spare elbow, and there was nothing else to do but to wait for one from the foundry.

The cause of this mishap, apart from the engineman's want of experience, was due to the steam driving the condensed water in the steam-pipes before it, to an elbow or corner, where the water, being pressed by the velocity and pressure of the steam, acted as a

bullet, and the steam as powder. This mishap stopped a flour-mill, and put the miller to much inconvenience; but neither the man nor the master was aware of the true cause.

The sudden expansion of steam has been used to throw balls out of a cannon. Now, water, being incompressible, is, in a sense, as solid as iron confined in a pipe, and therefore when a stop-valve is suddenly opened, and the pressure and velocity of the steam is opposed by water in the pipes, it is only reasonable to expect a smash.

Lastly. When the mind possesses no scientific principles for its guidance every act is invested with doubt, and any accident which may be caused through ignorance is surrounded with mystery.

CHAPTER XV.

STEAM-BOILER EXPLOSIONS.

All boilers, experience informs us, become gradually weakened by the working of destructive agents from the moment they are constructed till the time they are broken up. The progress of deterioration greatly depends upon the quality of their material, the design, and the amount of personal attention given to them; and therefore the progress of deterioration cannot be estimated at first sight. We are supposed to have more experience in the construction of steam-boilers than any of our predecessors. Yet, from time to time, we find boilers give way without a moment's warning, in consequence of imperfections or of mismanagement. There is not an atom of truth in many of the nonsensical hypotheses which are sometimes advanced to account for such accidents. The most common cause of boiler explosions is corrosion, which attacks a boiler, outside and inside. External corrosion may be occasioned by negligence of the most culpable description, or it may occur and work destruction through the ignorance of those who set the boiler in the brick-work. Culpable negligence is exhibited when the boiler plate is exposed to the atmosphere; the corrosion is then a slow process, but nevertheless it is a wasting away of the iron and its effects cannot be winked at.

It is seen when the water from the leaky gauge-cocks is allowed day after day to run down the front of the boiler. It is seen when a manhole-joint leaks and the condensed steam is allowed, from one week's end to another, to run down into the brickwork by the side of the boiler. It is seen when the condensed steam from the safety-valves, month after month, does the same thing. It is seen when the fireman or the engineman damps the ashes when they are close to the plates. All these occasions for corrosion are open to view; and it is well known that such leakages are causes of corrosion, more or less fatal according to the composition of the water. But the worst kind of corrosion is that which is due to the setting of the boiler on brickwork in such a way that the moisture from below and the drippings of water from the mountings above can find a lodgment in it. There, out of sight and out of mind, it eats the plate away to the thickness of sixpence. This is external corrosion, pure and simple, as it has not anything to do with the wear and tear of the boiler.

To prevent corrosive action of this kind all that is necessary is to set the boiler upon fire-lumps, as illustrated in Plates III., IV., V. Again, when boiler-mountings are permitted to leak, and the water runs down the side of the boiler, it is absorbed by the soot in the flue, and formed into a paste, which in contact with iron is a formidable enemy, and will reduce a new plate to a skeleton in an incredibly short period of time. The plan of building in a boiler with brick-work at both ends is out of date; so is any plan that savours of making a comfortable ledge for water or condensed steam in contact with iron.

Internal Corrosion.—This form of wasting away is not so rapid as external corrosion, when left to its course. But, provided that there were no such effect taking place, then the boiler internally fired would sooner or later succumb to internal corrosion, either extensive or local. The action of corrosive agents internally is chemical, galvanic, and mechanical. It is chemical when its effects resemble that of the work of ordinary rust—uniform. It is galvanic, when the stays' heads are eaten off, or when pit-holes are formed in the tubes and boiler-plates; or when the end of a gauge-glass is consumed in a very short time; galvanic action is very prevalent in boilers fed with water from a surface-condenser. Not long ago a hammer was taken out of a surface-condenser, having the soft portion of the eye eaten in holes, but the steel faces were untouched. It had been in the condenser nine months. Galvanism is a species of electricity excited, not by friction, but by establishing a communication between two different metals through the medium of a liquid: it is capable of producing an intense heat, and it also possesses energetic decomposing power. Mechanical action is exhibited by grooves, which are formed by alternate bulging and straightening, and is assisted by any acidity which may be present in the water. The mechanical action strains, frets, and fatigues the iron until the skin is broken, and the rapidity of the fracture is hastened by the action of acids in the water, which attack the most susceptible and sensitive parts, until a division or groove is made, when the water leaks through into the furnace or the flues. Grooving is generally found in the roots of angle-iron and flanged plates, and at the

longitudinal lap-joints of Cornish and of Lancashire boilers. This grooving action is due to the strain put upon a boiler whilst at work. It is quite certain that the contraction and expansion caused by opening the door for firing, and by urging the furnace, are very unequal, and cause unequal action of a serious nature; and although this action is known and specially dealt with by our very best boiler-makers, who employ "pockets," "gussets," and welded-in water-tubes, for insuring safety, yet the object may be frustrated by many circumstances beyond control. And what are they? Not electricity, not the spheroidal theory, nor the generation of explosive gases, nor a greater deterioration in the plates than what was expected under ordinary wear and tear. None of these things; but the want of *nous* on the part of the attendant. Overheating, overstraining, accumulation of deposit, wedged safety-valves, the conversion of the static pressure into a dynamic force.

Overheating may not cause a blow-up at the time, and it is well that cold water turned on to heated plates is not of itself capable of being at once converted into a large body of steam; otherwise many more boilers would have been burst. An engineman not long ago found the tube in a Cornish boiler overheated, and, fearing the consequences of his negligence, he chose to risk a kick from his boiler, rather than insure one from his master, and turned all feeds on, and so regained the proper water-level. But the mischief never ends here when such occurrences are smothered instantly. It is a well-known fact, if a piece of good ductile wrought-iron is heated to redness over a blacksmith's fire and then cooled suddenly in water, it becomes brittle and liable to snap. What

is there to hinder a piece of boiler furnace from becoming brittle when suddenly cooled by a pump throwing cold water upon it? The plate may support, in its crystallised condition, a crushing pressure for a time, but it will be liable to snap at any moment, as the atoms of which it is composed are loosened and disarranged, when any extra degree of expansion—tensile strain—may tear them asunder. When iron is overheated it becomes speedily oxidized, and its tenacity and cohesive force much reduced.

Not infrequently, over-heating is caused by the gauge-cocks being in a filthy condition, and not workable, the check taps being as fast as a rock—the boiler being practically charged like a cannon, ready at some convenient season to admit daylight through the roof of the boiler-house.

Sometimes overheating occurs in consequence of the boiler suddenly springing a leak, or bursting a tube. When such a surprise happens, an active fireman or engineman rakes the fire out of the furnace before much mischief is done. An engineman filled his boiler up after washing it out, and went home. He returned as usual next morning, and lighted the fire; presently he had a suspicion that all was not right, and upon his examining the boiler it was found to be empty. He examined the blow-off cock and all the mud-plugs about the boiler, but he could not discover any trace of the missing water. Where was it? In another boiler that had dropped its steam during the night, a vacuum was formed above the water, when the water of the boiler which had been filled was drawn through the feed-pipe, which was defectively arranged.

Overstraining may be occasioned by tampering with

the safety-valves, hanging weights on the le... wedging the lever down, in order to obtain pressure of steam. Or it may arise when, the power not being equal to the demand for stea... fires are urged; for, although steam may not at the valves, and the valves may not be lock... there is likely to be an excessive degree of ex... in the plates. This kind of straining takes pla... steam is taken from the boiler to supply an ad... engine. At the best of times, the expansion furnace, or the iron in contact with the fire much more per foot than in the surrounding Boiler plates in contact with the fire deterio... necessarily in proportion to the time they have work; but in proportion to the amount of h... has passed through them in a *given* time. The plate depends for its preservation upon the taking the heat out of it, as fast as it enters the furnace; but, in the absence of this co... it becomes overheated and evaporation is ... impeded, as the water is driven off by ... heat, which produces excessive expansion, ... consequence, buckling and grooving, and becomes ... employer of the caulking tools, and the arch destroyer of the boiler.

Take an internally fired boiler, urged by a fierce fire. The flue-tube expands; it becomes longer; and it therefore pushes both the back and the front plates Outwards. But if the end plates will not spring, then the tube becomes a bow, and the lower side is excessively strained by compression. Take a willow stick, with wood discs on each end, and bend it as a tube is bent, and as the fibres of the stick arrange themselves

to suit that position, so do the fibres of the iron; mark perpendicular lines at the end of the discs and note their altered position under the strain, and the probability is you will learn why grooving and fracture take place in the root of the angle-iron which holds the end plate to the shell of the boiler. Any kind of over-straining may be caused by unskilful enginemen. They may, for instance, blow off a boiler whilst it is very hot, and then turn cold water into it, either from the main or the tank—the intention being to wash it out. In some districts, such treatment, it is supposed, brings down a large quantity of scale. The scale is suddenly cooled and contracts more quickly than the boiler-plate, and therefore it is split up in consequence of the capricious manner in which contraction takes place amongst its own particles. Here there is not a thought as to how the contraction affects the boiler-plates. Of course they are affected like the scale, but upon a scale of greater magnitude, and extending over a larger period. The immediate effect is to produce leakage in the joints and the old fractures. The second effect is to make work for a boilermaker with a caulking-tool; the third effect, following from the second, is to cut the skin of the boiler; the fourth effect, following from the third, is corrosion; the fifth effect is that leakage, caulking, skinning, and corrosion are always at work; the sixth effect is a blow-up. It is thus seen that over-straining may be caused by an excess of heat, or by an excess of cold.

Accumulation of Deposit or Scale.—Too great an accumulation of scale, either general or partial, prevents the proper distribution of heat to the water, and the heat of the metal is then increased to too great an

extent. The ductility of the iron is changed, and caused to bulge and yield to the pressure.

Most kinds of water contain solid matter in sol or in suspension, and as the water is evaporated the matter remains and finds a resting-place on the top tubes or on the crown of the furnace and on the of the boiler. The nature of the deposit varies different kinds of water. There is a stone deposit a floury deposit. The former is sometimes called stone. The quantity of stone in solution waters, such as is taken from a brook in dry or pumped from a well where the surrounding is sand or rock is very considerable, varying from 150 grains in a gallon. Every particle of solid that enters the boiler must remain there unless off by priming, scumming, or blowing off. The must, if neglected, become a great evil. In fact boilers when opened have been found half full stonework. It is found that the layers of stone de- posit sometimes arrange themselves in such wise leave interstices to which the water can penetrate. When the water finds its way through these openings to the hot plate a local explosion takes place, which loosens the scale for some distance round. These explosions produce a rumbling commotion, and are not infrequently followed by the bulging of the furnace plates, and a trembling of the whole structure. It is often remarked by a witness at an inquiry into the cause of a boiler explosion that before the accident a rumbling noise was heard. Let us try to find an explanation for such a phenomenon.

If steam of a high temperature is turned into a tank of cold water, it will carry a considerable quantity

of water before it, which will strike the side of the tank with great force. In fact, if the tank is not very strong, it will become bulged outwards, and it may ultimately be fractured. The rumbling sound is not in the water or the steam. It is the muffled ring of the metal, produced by blows from the water. Heat is the agent which produces the mischief. If the incandescent boilerplate is supplied with a given quantity of water underneath a scale, its sudden formation into steam will scatter the adjacent scale and carry the water before it against the top or sides of the boiler. Scale having once been dislodged, fresh local contacts of water with the heated plate take place, and there is then a succession of cone-like forces of high-pressure steam producing a succession of blows, by driving the incompressible water against the crown of the boiler. It is the highly heated and elastic steam coming in contact with water, which produces the mischief. The hot plate is its base; its velocity is due to its elasticity. The energy of the steam is concentrated upon the water, which closes in upon it, and acquires a projectile velocity, as in an injector, so high that the point of impact rumbles under the blow, and the whole boiler gives notice.

The deposit may consist of a floury paste—carbonate of lime. When the deposit is allowed to accumulate in the boiler, the water, more or less, resembles a stir-about, which must be penetrated by the heated water or the steam, in order that it may reach the steam-space.

For this purpose, the water must be raised to a higher temperature than would be required if the water were comparatively clean, and consequently the tem-

perature of the plate is in excess of what it would under better management.

The accumulation of this kind of deposit does raise the alarm in the mind of enginemen like a layer of boiler-stone, but as a cause of over-heat is quite as potent.

With portable boilers and locomotive boilers change their water by changing the locality operations, much comparative experience of the two descriptions of scales is obtained. motive boilers perfectly water-tight with stone have, after working for a short time with water a floury scale, begun to leak. The stone-scale the tubes and the walls of the fire-box in If the scale happened to fall off without leakage, the effect would have been attributed superior quality of the water. But granting did leave the boiler-plates by virtue of the quality of the water, why should it make the joints open out?

The true cause is the expansion of the heating face in excess of that which took place while the scale was forming.

Take a pan coated with stone on the sides, and the bottom with a paste of flour and water, and filling it with water, boil the contents. The scale will fall off. The flour paste stopped the heat from passing rapidly through the bottom, and therefore the pan was raised to a higher temperature than usual; and not only is extra expansion caused, but if the paste be too thick, it will cause the bottom to be burned out; or, what is a better illustration of the influence of excessive temperature, the pan will become unsoldered.

When boilers are supplied with water which holds in solution chalk, limestone, &c.—carbonate of lime—they are not so ticklish to manage as those which are fed with water holding in solution sulphate of lime. This salt stops up the apertures of the feed-pipe, and gradually reduces the efficiency of the pump, an effect which alone is no small factor in the causing of a disaster. It is also very troublesome inside the boiler, as it accumulates between flue-tubes, and impedes the circulation of water. It also gets into the perforated holes in the steam-pipes, cutting off the supply of steam. But, more leaking, bulging, and fractures will follow the use of chalk and limestone water than what follows from the use of stone and rock-water.

Once more. We have a vessel half full of sand and the other half full of water, and if we make a hole in the bottom, the water will pass through the sand and escape; if we empty the sand out and replace it with flour, we shall find the water will not pass. We learn by induction that the pores of sand are not so fine as the pores of flour.

When the floury deposit becomes very thick by neglect in removing it, the plates and tubes are raised to an excessive temperature in order to make some impression upon the water. In course of time, the "nature" is burnt out of the iron, and there is then great danger of the furnace collapsing. When an overheated plate gives way, it is generally pressed down—collapsed—showing clearly where the plate had been overheated. A particular feature in the condition of a collapsed flue when crushed by over-pressure, and not weakened by fire, is that the flue is driven in on both sides of its axis.

Wedging down the Safety-valve.—This is a glaringly bad piece of foolery that is seldom harmless. When it is detected, the delinquent should be sharply dealt with. The safety-valves are adjusted to blow off, and to relieve the boiler of an excess of steam which, if it was retained, would distort and injure the permanent arrangements of the whole structure. When the safety-valve is pegged down tight upon its seating, there is no escape for the steam, which augments in force until the resistance of the boiler is overcome, and ultimately the weakest place suddenly yields, and destruction is inevitable. Let us look at the reckless danger of locking down valves, which is done every day. Sometimes the boilers are situated underneath office floors, factory floors, under the streets, the pavements, and the shops; an engineman locks down the valves of a new boiler, just from the maker's hands, and he thinks no danger can happen.

A boiler may be new to-day, and it may be exploded to-morrow under the pressure at which it was guaranteed to stand for several years. A boiler may be injured and weakened in transit between the boiler-maker's yard and that of the purchaser's, and who will say anything about it?

A boiler may be fixed in its position, and for want of proper support, its back is broken. A boiler may be properly tested, and the test may be overdone; so that after the test it is a weaker boiler than it was before it was tested, the strain it has suffered remaining undetected. A boiler may be weak before it is tested, and the weakness aggravated—not cured. A boiler, after it is subjected to intermittent expansion and contraction for a time, may open a hidden flaw in the plate.

A boiler may be made to sell, not to work under the most reasonable pressure. A boiler may have been burnt by an engineman and blown up by his successor in ignorance of the defect. But, however sound the original test and examination may have been, it is no answer to the folly of wedging down safety-valves.

The conversion of the static pressure of steam into a dynamic force.—When water flows through a pipe, if the tap be shut suddenly one will hear a sharp click and a rattle, and if the pipe be not very strong, it will burst.

Then why should we not burst a boiler in the same way in ignorance? Not with water, but with steam. The thing has been done, and has ended in a fearful loss of life. The steam from two boilers was allowed to flow into a third, and when the operation was finished the stop-valve was suddenly shut, and the steam that was issuing from these boilers being suddenly arrested and stopped in its motion, struck back forcibly into the boilers, like the water in an hydraulic tube, and impinged, as would a solid body, on the boiler-plates and burst them. There can be no question about the sudden retrocession of steam giving rise to an enormous force. By such force the bends and elbows of cast-iron and copper steam-pipes are frequently cracked when the valves and cocks are suddenly closed.

It may safely be concluded that the primary cause of boiler-explosions may be traced to corrosion of the plates, either as a uniform wasting of the surface, or as rapid local decline, rendering the plate too weak to bear the ordinary working pressure. The idea of high pressure is only a relative one, and can have reference only to the comparative strength of a boiler on which

the pressure is exerted. A boiler may be as safe w
150 lbs. pressure as another with 50 lbs., and eve
less liable to burst. High pressure exerted in a
of small dimensions may not amount to more
low pressure in a proportionately larger vesse
every boiler, steam of too high an elasticity f
resisting strength of the boiler may lead to an
sion, and of all things, great and small, there
so quiet, so insinuating, and so certain in
strength as corrosion: especially external
when the subtle "sweating" of the plates und
in mixture with soot or with moisture, is n
suspected. It attracts not the unskilled engi
does its work without a rumble, or a fract
blister. What fever, or the flush upon the ch
catching cough is to the human frame, corros
a boiler—a solemn warning.

CHAPTER XVI.

THE INDICATOR AND HOW TO WORK IT: WITH ILLUSTRATIVE DIAGRAMS.

Indicator.

Very accurate information respecting the character of steam and its behaviour in the cylinder, together with the condition of the valve and the motion, can be obtained by means of this instrument, originally invented by the celebrated Watt, and subsequently improved by Richards, Richardson, and others.

There is nothing so important about an engine as keeping the valve-motion in good working order. When the lead is absent, an unsteady action in the cylinder is set up; when it is slightly deficient, a portion of the stroke is performed with steam of a pressure much under the boiler pressure; when it is intact, and of the right amount, the engine works under the best conditions and with the minimum quantity of steam. How far this latter condition is attained can be found out by means of the indicator without removing the steam-chest or exposing the valves.

The instrument is not so highly appreciated as it deserves to be, for few private owners of engines know anything of its capability for telling tales, and the enginemen who know how to work it are few and far

between. *Fig. 26* represents a normal gram. It was taken at a slow speed, wh and the valve had sufficient time to movements with great regularity and p than when the engine runs at a highe make such a diagram the valve must be working order and well trimmed.

The indicator consists of a small ste

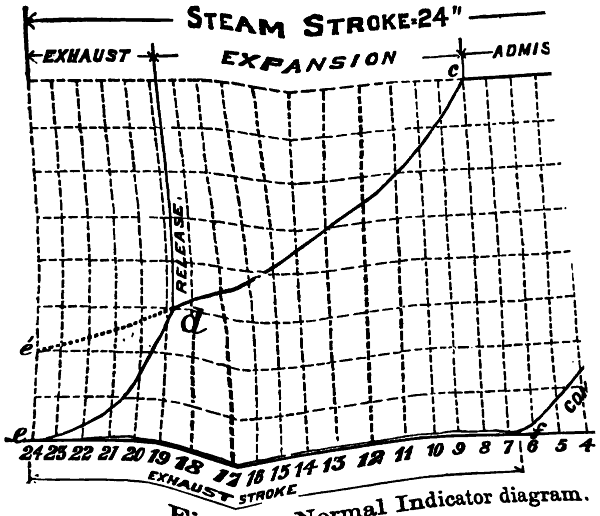


Fig. 26.—Normal Indicator diagram.

fitted with a piston held down with a spi The instrument is screwed into the cylin and when the communicating cock is op steam in the engine-cylinder it acts upon the the indicator, which is fitted at the top, o lever, which carries a pencil in contact with metallic paper coiled round a barrel fixed to

a vertical position, having upon *its* face a graduated scale.

The barrel turns on a vertical pivot, on which it receives a reciprocating movement by means of a cord attached to it at one end, and the other end to the cross-head of the engine; the movement then of the barrel represents the stroke of the piston. The movement of the small indicator-piston represents the pressure of the steam at every point of the stroke. The movement of the either is independent of the other. When steam is admitted to the indicator, the piston rises and falls in obedience to the pressure underneath it, proportionally compressing the spring, and the pencil rises and falls. The barrel is acted upon by the cord, and revolves to and fro. It should be stated that within the barrel there is a kind of watch-spring, which turns back the barrel to its original position as the engine finishes the reverse stroke. It should also be understood, that whilst the engine-piston moves, say, two feet, the length of a stroke, the motion of the barrel can be reduced by a system of levers or by a reducing-wheel to suit the length of the diagram required.

Richardson's continuous indicator is represented in Fig. 27. In the interior of the barrel, or paper-cylinder, there is a receptacle for a roll of paper, the end of which is brought out through a slot. It is thence passed round the cylinder, and is inserted again into the interior, when it is caught by a slotted roller, which is worked in one direction during the motion of the paper cylinder. When the diagram has all been taken, the length of paper can readily be pulled off the roller.

An indicator, Fig. 28, has recently been invented

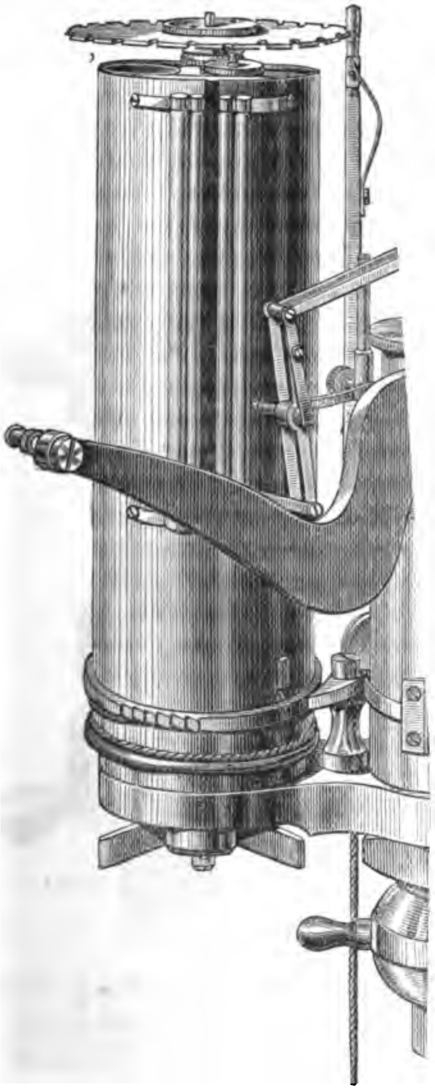


Fig. 27.—Richardson's Continuou

by Mr. E. T. Darke. In this instrument, every means has been taken to reduce the weight of the moving

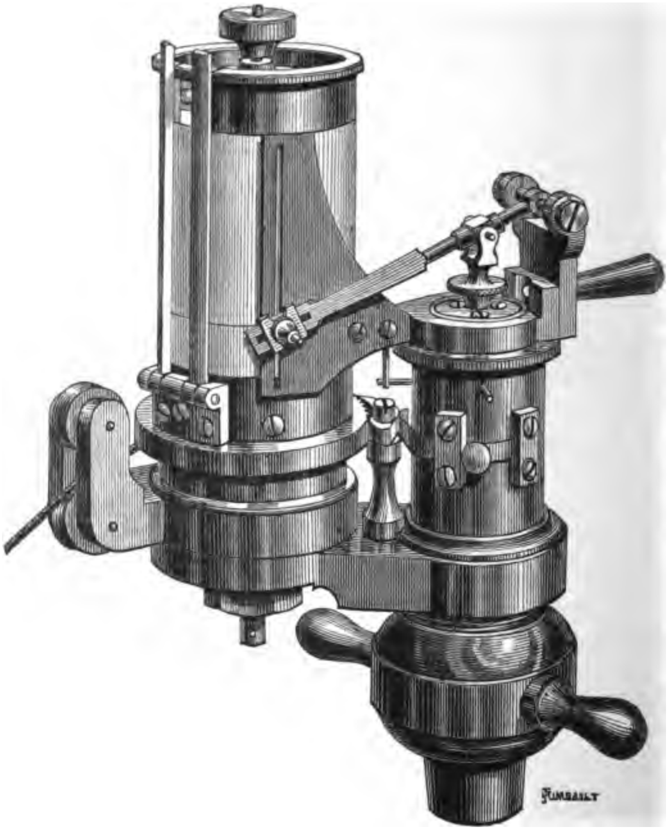


Fig. 28.—Darke's High-speed Indicator.

parts, and consequently their momentum, so as to obtain more correct diagrams at high speed than can be taken from other indicators. The piston has an area of only

¼ square inch. The spring is very small in diameter, the piston-rod is hollow and short. The stroke of the piston is from ¼ inch to ⅜ inch, and the greatest length of diagram is 3¼ inches. The pencil-motion is made of one piece of steel, fitted at one end to and sliding in a hollow crosshead on steel centres, and carrying at the other end a small sliding-block, through which the pin, or pencil as it may be called, passes. The pin moves upon the paper drum through a slot or guide, swivelled to the top of the steam cylinder of the indicator. There is, of course, provision made for the sliding of the pencil in the pencil-arm, to enable the pencil to follow a straight upright line, whilst the arm moves radially. The paper-drum is made available for the reception of the indicator-paper, which is placed in the interior in a roll—a continuous sheet—and may be drawn through a slot at the side as required, and torn off when a diagram has been taken.

To take a diagram by the indicator, from the cylinder of a non-condensing engine, the first thing is to revolve the barrel. The pencil traces a straight line, which is called the atmospheric line, or the line which corresponds to the absolute pressure of the atmosphere, 14·7 lb. per square inch. The cock is now opened, and steam is let into the barrel of the indicator. It does not signify at what point of the stroke this is done; but to simplify the explanation, we will suppose that it is done at the commencement of the stroke *a*, Fig. 26. The steam then instantly drives the piston, and with it the pencil, upwards. The pencil rises as high as the pressure in the engine-cylinder will lift it, to the level *b*, where it remains so long as the pressure underneath it remains unchanged. Meanwhile the

barrel is pulled round, and no other change takes place until the point *c* is reached, where the steam is cut off by the valve, which closes the steam-port. Expansion commences, and the pressure in the cylinder is gradually reduced to the pressure indicated by the point *d*. If steam of 100 lbs. total pressure, or 85 lbs. effective pressure, in the cylinder is cut off at 8 inches of the stroke, and is allowed to expand through another 8 inches, the volume of the steam is doubled, and the total pressure is reduced one-half (to 50 lbs.), giving an effective pressure of 35 lbs.; and if it is allowed to expand through another 8 inches of stroke, the volume is trebled, and the total pressure is reduced to one-third. This law of the expansion of steam is known as Boyle's law, or Mariotte's law, after the name of the discoverers; and it constitutes the basis upon which calculations of the expansive action of steam are made. When it is known what the pressure of steam is in the cylinder before the valve closes the port, the pressure of the steam when the valve opens the port for exhaust can be calculated. At *d* the pencil suddenly drops, which is owing to the valve having opened the exhaust-port to the atmosphere or the condenser, and at once joins the atmospheric line at the eduction corner *e*. Now this indicates that the exhausted steam is cleared out of the cylinder. If there were any steam in the cylinder of a higher pressure than that of the atmosphere, it would act upon the piston of the indicator and prevent the pencil falling so low as the atmospheric line.

Should the exhaust-steam meet with any obstruction, as too much inside lap, or contracted passages, the resistance will be shown by the elevation of the pencil

above the atmospheric line, which represents a clear cylinder. From e to f it will be seen that there is a small quantity of steam in the cylinder acting upon the indicator. As the piston advances beyond the point f, this steam is compressed, and, by Mariotte's law, when the volume is reduced one-half, the pressure is doubled; and if the volume is reduced one-half again, the pressure is again doubled. The gathering of the steam into a heap at the end of the cylinder, and its being compressed by the advancing piston, are reflected by the indicator, which shows what compression there is. If there were no compression whatever, the piston would have no help in turning the centre. Compression acts as a cushion on which the piston changes the direction of its motion, and it prevents the change being sensibly felt in the movements of the engine.

From f, then, the pressure is first raised in consequence of a small quantity of steam being compressed, and the pressure is augmented before the piston reaches the end of the stroke by the pre-admission of steam from the valve-chest, when the pencil of the indicator at once rises to b. The admission of the steam to the cylinder before the piston has finished the stroke is due to the lead of the valve. Too much lead causes too much counter-pressure, and too little lead gives rise to unsteady motion of the piston when turning the centre.

We have traced the formation of the diagram through one revolution, and have noted the point of admission, b, the point of expansion, c, the point of release, d, the eduction point, e, and the point where compression commences, f.

A pair of indicator diagrams, taken from both ends

of the steam-cylinder of a condensing engine, is illustrated by Fig. 29. There the form of the diagram is less sharply defined than in Fig. 26, which represents a diagram taken at a very low speed. The annexed diagrams were taken at the regular working-speed of the engine. The treatment of the movements of the

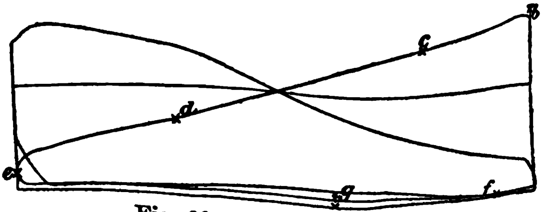


Fig. 29.—Indicator diagrams.

steam may be traced as follows for the right-hand figure:—

b, Point of admission.
bc, Period of ditto.
c, Point of expansion.
cd, Period of ditto.
d, Point of release.
de, Period of ditto.
f, Point of compression.
fb, Period of ditto.
g, Back-pressure.

Defects as pointed out by the Indicator.—If, instead of a nice sharp corner *b*, Fig. 29, we get one slanting to the left, making a round large corner towards *c*, it shows that the valve is without lead, and that the excentric requires to be shifted a little more in advance of the crank, or it may be that the valve-spindle is too long. If the lead-corner *b* is too full, the valve has too much lead, and compression will commence early, and the excentric requires to be shifted towards the crank or backed. If the admission period slopes too much towards the expansion corner *c*, instead of showing a regular maintenance of pressure from *b* to *c*, it shows

that the steam is wire-drawn, that is, that the steam is prevented, either by the regulator or by the valve, from freely entering the cylinder, and that the pressure is reduced between *b* and *c* instead of being constant. This decline may be caused by the steam-ports not being properly proportioned, so as to admit sufficient steam through them in time to follow up the piston with a *full* pressure, and effect a full steam-line, or it may be caused by the steam being condensed in the cylinder, or by water primed over with the steam. It must be understood, however, that the maximum pressure in the cylinder is not absolutely maintained along the whole of the admission-line with perfect regularity, as the reduction of pressure and the absence of sharp corners at the expansion-point and the release-point is partially due to speed, and partially to the valve closing the ports gradually to the steam, and not suddenly cutting off or suddenly releasing it.

The maximum opening of the port is attained midway between the admission-point and the point of cut-off; and it is here that the valve begins to close, and it may be stated that at all ordinary speeds the steam really begins to expand before it is actually cut-off. That it is so, is demonstrated by the declining line *b c* upon the diagram, Fig. 29. After the steam is actually cut off, it is no longer subject to any change, with proper working valves, except that which is fixed by the law of expansion, and the line from *c* to *d* should be nearly hyperbolic in its character—that is to say, the curve should follow Boyle's law. But there are many causes operating within the cylinder to prevent the steam expanding precisely according to that law. If the cylinder is colder than the steam, then condensation

plays a part. If the steam is accompanied with water, or if water is already in the cylinder, the temperature of the steam will rapidly fall. It is in the interval between *c* and *d*—the expansion period—where we must look for signs of a valve leaking. By referring to Fig. 30, it will be seen that the expansion-curve is convex at *b* instead of being concave, which is caused by

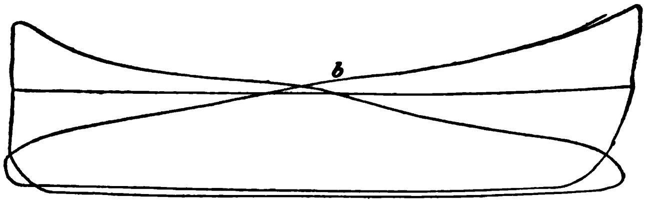


Fig. 30.—**Indicator diagram showing the effect of leakage.**

the valve "blowing," and admitting steam to the cylinder, when it was supposed to have been cut clean off. The form of the expansion-curve is modified by the extra pressure thus caused disturbing the indicator, and raising the pressure of the steam in the cylinder when the pressure should have been more regularly decreasing.

The expansion line and the exhaust line run into one apparent curve, for at working speeds the whole of the steam does not immediately leave the cylinder when the exhaust is opened, and the portion lingering behind regularly expands to the end of the stroke. That steam produces a useful effect on the piston after the exhaust is open, is seen in the indicator diagram, of which the area is augmented by the exhaust-pressure in the later portion of the diagram. If the eduction corner, Fig. 29, is rounded too much, and the back-pressure

line remains too far from the atmospheric line with excessive and early cushioning at *f*, it is a sign that the valve, having too much inside lap, cannot clear the cylinder of steam before the port is closed. When engines suffer from this defect, they are said to be "wrapped" up, and a considerable proportion of power may be lost by excessive compression. If the exhaust-line runs up at the point of compression *f*, and attains a considerable height, forming a large corner before the steam is admitted, it shows that the valve requires more lead, in order to admit sufficient steam to the piston to keep up the working speed and pressure at the turn of the stroke. If the opening of the port for the admission of steam is late, the admission-corner is rounded off as already stated. So we have gone round the diagram.

When a diagram exhibits defects, the first thing is to observe whether the defects are shown all round the diagram. If they are, they may be rectified by shifting the excentric. If all the movements are late, the excentric must be moved forward; and if they are too early, it must be shifted backward. But if the defect is only local, and confined to one edge of the valve, then the remedy is to shorten or lengthen the valve-rod. Suppose the slide was producing a good diagram, and that for the sake of experiment the excentric was advanced, all the points of distribution would be affected, of course. The admission would be earlier, the cut-off earlier, the exhaust earlier, and the compression earlier. If we obtained in practice a diagram showing that all these points took place too early, the backing of the excentric would effect the required alteration. Again, if the valve be right, and the excentric be then

backed, all the points—admission, cut-off, exhaust, and compression—would be affected, and the steam would be late everywhere. The piston would reverse its course before steam was admitted, the expansion would not take. place until the piston was well down the cylinder, and the exhaust would take place when the piston was about to change its course again; and this last defect would be the cause of much back-pressure on the piston.

Causes affecting the edges of the valve.—Suppose the slide of an engine working all right and that the slide-rod were to be shortened; the effect would be that the steam would enter the cylinder on the top stroke earlier, but the cut-off and the exhaust would be later. For the bottom stroke, of course, the very opposite effects would occur. The steam would be *late* in entering the cylinder; it would be cut-off and exhausted *earlier*. If the valve-rod were lengthened, that which happened to the top stroke with a shortened valve-rod would now occur on the bottom stroke, and what occurred on the bottom would happen on the top. For instance: in vertical engines it is necessary to give more steam on the bottom than what is given to the top, to counteract the weight of the piston and the connecting-rod and to assist in making the up-stroke.

Figure 31 is a diagram taken from a vertical engine, and it shows that the engine received more steam on the top than on the bottom. This engine, to all appearance, worked well, though it laboured heavily when making the downward stroke. To any one not experienced in detecting defects, the engine seemed perfection, but a slight increase of steam admitted at the bottom made an unlooked-for improvement. The

engine turned the dead centre with ease, and ran freely at high speed with less thumping and consuming less fuel.

Here was a case which affected the edge of the

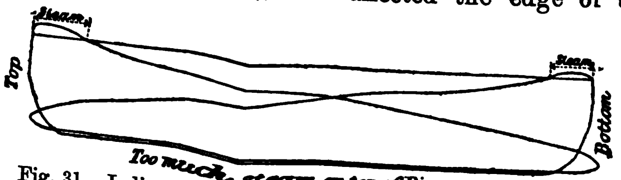


Fig. 31.—Indicator diagram from a vertical steam-engine.

valve. How was the improvement to be made? What did the valve require? It required to be raised, and that was accomplished by inserting a $\frac{1}{16}$-inch liner between the butt-end of the excentric-rod and the excentric-hoop.

This card, Fig. 32, was taken after the alteration of lifting the valve $\frac{1}{16}$-inch was done. It will be seen from this example that, if the engine had happened to

Fig. 32.—Indicator diagram from a vertical cylinder, after the valve was re-set.

have too much steam on the bottom, the necessary alteration could have been effected by taking out a liner or shortening the rod.

To work out Diagrams.—In compound condensing-

ıgines the steam is either exhausted directly from one ylinder into the other, or it is exhausted into an ıtermediate receiver, whence it is admitted into the econd cylinder. The second plan is followed when ıe high-pressure and low-pressure cylinders work ırough their connecting-rods on cranks at right ıgles to each other; because, as is evident, when one iston is at the end of the stroke the other piston is about half way, and the receiver is required for olding the exhaust-steam from the high-pressure ylinder until the low-pressure piston arrives at the ıd of the stroke, and is in readiness to receive it. fter the steam has worked the low-pressure piston the end of the stroke, it is then exhausted into the ndenser. Such is the arrangement of the engines om which the cards were taken which we are about examine.

The double diagram, Fig. 33, taken from the top ıd the bottom of the cylinder, is divided into ten ual parts; there are nine whole parts, and the two ıaller ones at each end are equal to one whole, aking ten equal parts.

The scale, said to be $\frac{1}{32}$-inch, represents 1 lb. pressure r square inch of steam on the piston for each -inch. For so many $\frac{1}{32}$-inches as are contained in the dinates to the atmospheric-line reaching between the am-line and the exhaust-line there are as many unds of pressure per square inch upon the piston.

Taking the diagram from the bottom of the cylinr, ordinate No. 1 is found, by measurement with a le, to contain 44 thirty-seconds of an inch, and lbs. is set down beside it. At No. 2 there are thirty-seconds of an inch, and so on to the

tenth ordinate. Summing up the ten entries of pressure there is a sum of 230·5 lbs. This divided by 10 gives 23·05 lbs., which is the mean-pressure of the steam for the whole of the bottom stroke.

The top side is calculated in the same way, and gives 22·05 lbs. for the mean-pressure. The sum of 23·05 lbs. and 22·05 lbs. = 45·10 lbs., and this divided by 2 gives 22·55 lbs. mean-pressure for one double stroke.

The diagram, Fig. 34, is calculated in the same way

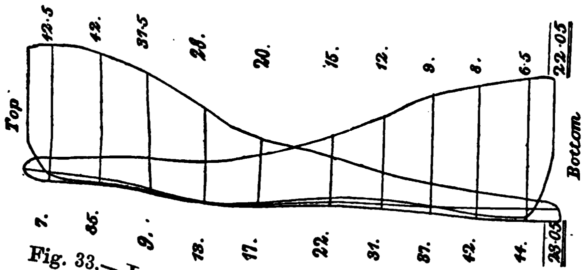


Fig. 33.—Indicator diagrams—measurement of power.

Diameter of cylinder, $44\frac{1}{4}$ inches. Stroke, 45 inches. Scale, $\frac{1}{32}$. Revolutions, 45 per minute. Steam cut off, 15 inches travel of piston. Steam pressure, 45 lbs. per square inch. Indicated horse-power, 359·38.

as the one just explained, but when dealing with a low-pressure diagram there are several points to be noticed. The diagram made by the indicator-pencil is nearly all below the atmospheric-line, as the steam in the low-pressure cylinder was acting on the piston against a vacuum formed on the other side of it, and therefore it was doing useful work, instead of having to overcome atmospheric resistance, which had been removed by the condenser and air-pump. The power exerted by

the steam upon the piston is thus made available for working the machinery. In the diagram under consideration, the steam was admitted to the cylinder just a little above atmospheric-pressure, but acting upon a piston and in a cylinder from which the atmosphere had been withdrawn, we see from the diagram the steam expanded to 10 lbs. below the atmospheric-line. This additional work was obtained by condensing the steam and pumping the air out of the cylinder, so that the piston was free to descend when urged by low-pressure steam.

The total number of pounds pressure = 12·90 lbs. for the top and bottom stroke, which divided by 2 = 6·45 lbs., for the mean-pressure on the piston throughout one double stroke, or for one revolution of the engine.

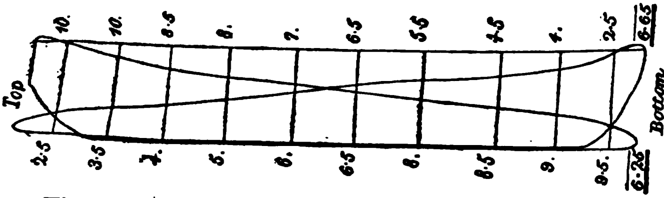


Fig. 34.—Indicator diagrams—measurement of power.

Diameter of cylinder, 79 inches. Stroke, 45 inches. Scale, $\frac{1}{12}$. Revolutions, 45 per minute. Pressure in receiver, 1½ lb. per square inch. Indicated horse-power, 323⅝.

To work out the Indicator Horse-power.—The measure of a horse-power is a working force that will raise 3,000 lbs. one foot high in *one minute*, or it may be fined as 33,000 *foot*-pounds in one minute. Indicated horse-power is ascertained from diagrams taken h the indicator from the top and the bottom of the

cylinder of the engine when at work. The mean or average pressure during the stroke having been obtained in the way we have explained, the calculation is generally made by squaring the diameter of the cylinder, and multiplying the product by ·7854, which gives the area of the piston, on which the pressure of the steam is exerted, then multiplying by the mean or average pressure per square inch throughout the stroke, then by the number of revolutions made by the engine per minute. The product expresses the total work done in one minute. This total is divided by 33,000 to find how many times 33,000 lbs. have been lifted one foot high in the minute. The quotient is the actual indicator horse-power.

Example from the indicator card we have examined, worked out, at the end of this work.

Nominal Horse-power is generally calculated from the area of the piston as a datum, without any reference to the speed of the piston or to the pressure. It may be judged that the term may have very various significance. There is no fixed area for horse-power. The term is simply a commercial expression.

CHAPTER XVII.

ARITHMETICAL CALCULATIONS FOR ENGINEMEN.

SIGNS USED IN CALCULATION.

$=$	signifies	Equality	as 3 added to 2	$= 5$
$+$	,,	Addition	,, $4 + 2$	$= 6$
$-$	,,	Subtraction	,, $7 - 2$	$= 5$
$\times$	,,	Multiplication	,, 6×2	$= 12$
$\div$	,,	Division	,, $12 \div 2$	$= 6$
$: \, :: \, :$	,,	Proportion	,, 2 is to 3 as 4 is to 6	
$\sqrt{}$	,,	Square root	,, $\sqrt{16}$	$= 4$
$\sqrt[3]{}$	,,	Cube root	,, $\sqrt[3]{64}$	$= 4$
3^2	,,	3 is to be squared	,, 3^2	$= 9$
3^3	,,	3 is to be cubed	,, 3^3	$= 27$
$\overline{2 + 5} \times 4$	,,	that 2 and 5 = 7, and four times 7		$= 28$

$\sqrt{5^2 - 3^2} = 4$. This reads, 3 squared taken from 5 squared, and the square root extracted . $= 4$

$\sqrt[3]{\dfrac{10 \times 6}{15}} = 1{\cdot}587$, reads, 10 multiplied by 6 and divided by 15; the cube root of the quotient . . $= 1{\cdot}587$

SIMPLE PROPORTION.

When we have three numbers given, this rule teaches how to find a fourth number, which may have the same proportion to the third number that the second has to the first.

Thus, if the three given numbers be 3, 9, 4, it is required to find a fourth number which will have the same proportion to 4 that 9 has to 3; now the 9 is 3

times the 3, therefore the required nu
times the 4, that is 12.

To express proportions the numbers
thus 3 : 9 :: 4 : 12, and reads thus 3 is to
RULE, WITH EXAMPLE.—Place them
and multiply the second and third

together, and divide by the first.

To 3.	6.	12	find a fourth proportional.	
" 6.	12.	4	"	"
" 10.	150.	68	"	"
" 68.	1020.	10	"	"

If 4 lbs. of tallow cost 20 pence, w
cost?

RULE, WITH EXAMPLE.—In this qu
two things mentioned, tallow and mo
required is the price, money,
Put down the money—20 pence—for
This is always so, that is, the third ter
kind as the answer required, and this is
ing. If the *answer* is to be greater than
the greater is placed second, and if it is
the less, of course, seco
placed first, and the
tion before us requires an answer g
third term, and is worked out thus—

$$4 \text{ lbs.} : 16 \text{ lbs.} :: 20 \text{ pence}$$

$$\begin{array}{r} 20 \\ \hline 4)\;320 \\ \hline 80 \text{ pence} = 6s.\ 8d. \text{ Ans.} \end{array}$$

If 6s. 8d. will purchase 16 lbs. of tall

pounds will 1s. 8d. buy? Here the answer is to be less than the third term, and it is pounds of tallow and not money; therefore observe,

```
Pence.  Pence.   lbs.
 80  :   20  : : 16
         16
        ---
        120
         20
        ---
   80)  320
        ---
      4 lbs.   Ans.
```

DECIMALS.

By decimals are meant tenths. Decimal arithmetic is the simplest possible method of working calculations.

It is worthy of special attention that, in decimals, the dot performs a very important part: separating integers from ciphers, or the fractional parts from a whole. Decimals, contrary to vulgar fractions, are written in one line like integers; and they are, in all respects, worked out in a plane-sailing way.

Decimal fractions are written thus . . . ·25 : ·5 : ·75 :
Their equivalents in vulgar fractions are written . $\frac{1}{4}$ $\frac{1}{2}$ $\frac{3}{4}$

The value of a decimal is altered by placing ciphers to the left, but not by placing ciphers to the right.

Thus ·05 = $\frac{5}{100}$; and, by placing a cipher to the left, the decimal becomes ·005, or $\frac{5}{1000}$, which is ten times less than $\frac{5}{100}$.

ADDITION OF DECIMALS.

Add 4·15; ·002; ·3:—

```
4·15
 ·002
 ·3
-----
4·452
```

Observe the position of the dot.

SUBTRACTION OF DECIMALS.

RULE.—If the number of decimal places be not the same in all the fractions, annex so many ciphers to the right hand as will render it so. We do not alter the value of the fractions so supplied, but they are reduced to the same denominator.

Subtract 106·125 from 125·5.

```
  125·500
  106·125
  -------
   19·375     Ans. 19⅜.
```

MULTIPLICATION OF DECIMALS.

RULE.—Arrange the numbers as if they were integers.

Multiply 148·74 by 2·67.

```
  148·74 } Observe 4 decimal
    2·67 }   figures used.
  ------
  104118
  89244
 29748
 --------
 397·1358 (Four Decimals cut off.)
```

NOTE.—Count the number of decimals in both the multiplicand and the multiplier, and point off as many figures from the right hand of the product.

Multiply ·02 by ·045.

```
   ·02
   ·045
  ------
  ·00090
```

In counting the number of decimals in the multiplicand and multiplier to point off in the product, if there are not sufficient figures in the product, place ciphers to the left, and prefix the dot as above.

DIVISION OF DECIMALS.

RULE.—Divide as in whole numbers, and mark off in the quotient as many decimal places as the dividend has more than the divisor.

Divide 72·125 by 6·25.

```
Dvsr. Dividnd. Quot.
6·25)72·1250(11·54
     62 5
     ----
      9 62
      6 25
      ----
      3 375
      3 125
      -----
        2500
        2500
        ----
        ....
```

The cipher in the dividend is brought in and shown above as making the number of decimals in the dividend equal to the number in the divisor and quotient together.

REDUCTION.

To reduce a Vulgar Fraction to a Decimal.

RULE.—Divide the numerator by the denominator, annexing as many ciphers to the numerator as may be necessary. Point off as many decimal places in the quotient as there are ciphers annexed to the numerator.

Reduce $\frac{1}{4}$ to a decimal.

```
4)100        Observe 2 ciphers added.
  ---
  ·25 Ans.      „     2 decimals cut off.
```

Reduce $\frac{3}{4}$ to a decimal.

$$4)3\hat{0}\hat{0}$$
$$\underline{\underline{\cdot75}}\ \textbf{Ans.}$$

Reduce $\frac{7}{8}$ to a decimal.

$$8)7\hat{0}\hat{0}\hat{0}$$
$$\underline{\underline{\cdot875}}$$

The annexed table, of decimal equivalents of the fractional parts of an inch, is calculated as above.

Vulgar Fraction.	Decimal Equivalent.	Vulgar Fraction.	Decimal Equivalent.
$\frac{1}{32}$	·03125	$\frac{1}{2}\ \frac{1}{32}$	·53125
$\frac{1}{16}$	·0625	$\frac{1}{2}\ \frac{1}{16}$	·5625
$\frac{3}{32}$	·09375	$\frac{1}{2}\ \frac{3}{32}$	·59375
$\frac{1}{8}$	·125	$\frac{5}{8}$	·625
$\frac{1}{8}\ \frac{1}{32}$	·15625	$\frac{5}{8}\ \frac{1}{32}$	·65625
$\frac{3}{16}$	·1875	$\frac{5}{8}\ \frac{1}{16}$	·6875
$\frac{1}{8}\ \frac{3}{32}$	·21875	$\frac{5}{8}\ \frac{3}{32}$	·71875
$\frac{1}{4}$	·25	$\frac{3}{4}$	·75
$\frac{1}{4}\ \frac{1}{32}$	·28125	$\frac{3}{4}\ \frac{1}{32}$	·7812
$\frac{1}{4}\ \frac{1}{16}$	·3125	$\frac{3}{4}\ \frac{1}{16}$	·8125
$\frac{1}{4}\ \frac{3}{32}$	·34375	$\frac{3}{4}\ \frac{3}{32}$	·84375
$\frac{3}{8}$	·375	$\frac{7}{8}$	·875
$\frac{3}{8}\ \frac{1}{32}$	·40625	$\frac{7}{8}\ \frac{1}{32}$	·90625
$\frac{3}{8}\ \frac{1}{16}$	·4375	$\frac{7}{8}\ \frac{1}{16}$	·9375
$\frac{3}{8}\ \frac{3}{32}$	·46875	$\frac{7}{8}\ \frac{3}{32}$	·96875*
$\frac{1}{2}$	·5	1	1·000

To reduce Money, &c.

RULE.—Divide by as many of the lower denomination as make one of the higher, annexing ciphers at will. If there be several denominations, proceed in the same manner with each, beginning with the lowest denominator.

* Reads—Decimal nine six eight sev n five.

Reduce 12s. 8¼d. to the decimal of a pound sterling.

(4 farthings = 1 penny	4)1·00
(12 pence = 1 shilling	12)8·2500
(20 shillings = £1	20)12·68750
	·634375 = decimal value of 12s. 8¼d.

To re-value this decimal, multiply it by the various fractional denominations of the whole number, cutting off from the right hand of each product, for decimals, a number of figures equal to the number of decimals given, then multiply the remainder by the next lower denomination, and proceed until the lowest is reached.

·634375 20	6 decimals.
12·687500 12	6 decimals cut off.
8·250000 4	" "
1·000000	" "
Ans.	12s. 8¼d.

To find the Value of a Decimal.

RULE.—Multiply the decimal by the number of the next lower denomination which is equal to one of its present denomination. Cut off as many places as there are places in the multiplicand.

Find the value of ·75 foot.

$$\begin{array}{r} \cdot 75 \\ 12 \\ \hline 9\cdot 00 \end{array}$$

Ans. 9 inches.

Find the value of ·3875 of a £.

$$\begin{array}{r} \cdot 3875 \\ 20 \\ \hline 7\cdot 7500 \\ 12 \\ \hline 9\cdot 0000 \end{array} \quad \text{Ans. 7s. 9d.}$$

Find the value of ·375 ton.

$$\begin{array}{r} \cdot 375 \\ 20 \\ \hline 7\cdot 500 \\ 4 \\ \hline 2\cdot 000 \end{array} \quad \text{Ans. 7 cwt. 2 qrs.}$$

INVOLUTION.

When a number is multiplied by itself, the product is called a power, and the number multiplied is called the root.

Thus $2 \times 2 = 4$. Here 4 is the square or second power of the root 2. Again, $2 \times 2 \times 2 = 8$. Here 8 is the third power of 2.

EVOLUTION.

Evolution is the method of finding the root of a number.

To extract the square root of any given number is to find a number which, when multiplied by itself, will produce the given number.

Extract the square root of 55225.

Rule, with Example.—Divide the given number into periods, that is, set a dot over the unit and right-hand figure, and then over every alternate figure towards the left. Find the square root (2) of the first

period (5), and place it in the quotient. Subtract the square of it (4) from the first period (5), and to the remainder annex the next period (52) for a dividend. Double 2, the root already found for a divisor, and place it (4) to the left of the dividend, looking upon it as 40 and not 4. After finding that this divisor (40) will go 3 times in the dividend (152), place the figure representing the number of times in the quotient, and also in the divisor, making the latter 43; then multiply the 43 by 3, and subtract the product. Bring down another period (25).

In forming the second divisor, 465, double the last figure (3) in the first divisor, and look upon it as 460. After finding that this divisor (460) will go 5 times in the dividend, place the 5 in the quotient and divisor, making the latter 465; then multiply the 465 by the 5 just placed in the quotient, and subtract the product, which leaves nothing; 235 being the answer.

```
       55225(235
       4
       ----
    43)152
       129
       ----
  465) 2325
       2325
       ====
```

What is the square root of 177241?

```
       177241(421
       16
       ---
   82) 172
       164
       ----
  841)  841
        841
       ----
        ...
       ====
```

EXTRACTION OF THE THIRD OR CUBE ROOT.

To extract the cube root of any given number is to find a number which, when multiplied twice by itself, will produce the given number.

RULE, AND EXAMPLE.—Make a dot over every th figure, beginning at the unit or right-hand figure ri to the left with whole numbers and towards the in decimals.

What is the cube root of 884736? Place the root of the first period (884) in the quotient, on the ri and its cube (729) under the first period (884). tract, and to the remainder (155) bring down the period of three figures (736). Multiply the squa the quotient (9 × 9 = 81) by 300 for a divisor. how often it is contained in the dividend, and pu number (6) in the quotient. Multiply the divisor (24 by this number (6). Add to the product the a of all the figures in the quotient (9), multiplied b —except the last (6)—and the product by the sq of the last.

To these figures add the cube of the last figure in quotient, and subtract the sum of the whole from dividend; thus—

$$\sqrt[3]{884736}\,(96\ \text{Ans.}$$

729

9 × 9 × 300 = 24300)155736*
145800
145800 = divisor × 6
9720 = 9 × 30 × 6^2
216 cube of 6

155736* see figs. in dividend above.

Another way:—
What is the cube root of 10648?

$$\sqrt[3]{10\dot{6}4\dot{8}}(22$$
$$8$$
$$2 \times 2 \times 3 = 12)2648$$

Here, after squaring the root of the first period, we multiply it by 3 = 12, and, rejecting the units and tens, we find the divisor is contained twice in the dividend, which is put in the quotient, making 22, the cube root of 10648.

Proof—

```
      22
      22
      --
      44
     44
     ---
     484 square of 22
      22
     ---
     968
    968
   -----
   10648 cube of 22
```

MENSURATION, ETC.

The kinds of measurement are three, viz., Lineal, Superficial, and Solid.

Lineal measure respects or refers to length only, as twelve inches. *Superficial* measure refers to length and breadth, as twelve inches in length, and twelve inches in breadth = 144 square inches, which is equal to 1 square foot. *Solid* measure refers to length, breadth, and depth, as twelve inches in length, twelve inches in breadth, and twelve inches in depth = 12 in. × 12 in. × 12 in. = 1728 cubic inches = 1 cubic foot.

Lineal Measure.—A connecting-rod of an engine is, say, 6 feet 6 inches from the centre of the big end *to the* centre of the little end; from the centre of the big end to the outside of the strap the length is 6 inches; from

the centre of the little end to the outside of the strap the length is $4\frac{1}{2}$ inches. Required the total length.

6 ft. 6 in. + 6 in. + $4\frac{1}{2}$ in. = 7 ft. $4\frac{1}{2}$ in.

Superficial Measure.—A slab of iron is 12 feet 6 inches long and 1 foot 3 inches broad. What is the superficial measurement or area of the slab?

This can be found in four several ways, viz., by Decimals, by Whole Numbers, by Cross-Multiplication, and by Practice. Thus—

(1) Decimals.

```
           12·5
            1·25
          ------
             625
            250
           125
          ------
Feet      15,625
              12
          ------
Inches     7,500
               4
          ------
Quarters   2,000
```

(2) Whole Numbers.

```
    150 inches
     15 inches
    ---
    750
   150
   ---
144)2250(15 feet
    144
    ---
     810
     720
     ---
      90
      12
     ---
144)1080(7 inches
    1008
    ----
      72
       4
     ---
 144)288(2 quarters
     288
     ---
     ...
```

(3) By Cross-Multiplication.

```
12 ·6
 1 ·3
--------
12 ·6
 3 ·1 ·6
--------
15 ·7 ·6
```

(4) By Practice.

```
         12 ·6
          1 ·3
        -------
         12 ·6
3 = 1/4   3 ·1½
        -------
         15 ·7½
```

Although the fourth method is the shortest, the first is much more generally practical, under the many changes which crop up in dealing with fractional parts; and in order to initiate enginemen into the practice of using them, we have given examples how to work them.

Solid Measure.—A block of iron is 12 inches long, 12 inches broad, and 12 inches deep. How many cubic inches does it contain?

$$\begin{array}{r l} 12 & \\ 12 & \\ \hline 144 & \\ 12 & \\ \hline 1728 & \text{cubic inches.} \end{array}$$

A sheet of iron is 120 inches long, and at one end it is 34 inches wide, and at the other end 10 inches. What is the superficial measurement?

$$\begin{array}{r r l} & \text{Inches.} & \\ & 34 & \\ & 10 & \\ \hline & \tfrac{1}{2})44 & \\ \hline \text{1 foot 10 inches = inches} & 22 & \text{The medium between the least and greatest length.} \end{array}$$

$$\begin{array}{r r r} & \text{ft.} & \text{in.} \\ & 10 & 0 \\ & 1 & 10 \\ \hline & 10 & 0 \\ & 8 & 4 \\ \hline \text{Ans.} & 18 & 4 \end{array}$$

Solid Measure.—A block of iron is 12 inches long, 12 inches broad, and 12 inches deep. How many cubic inches does it contain?

$$\begin{array}{r} 12 \\ 12 \\ \hline 144 \\ 12 \\ \hline 1728 \end{array} \text{ cubic inches} = 1 \text{ cubic foot.}$$

A boiler-plate is 6 feet 9 inches long, 4 feet 6 inches wide, and $\frac{3}{8}$ths of an inch thick. How many cubic inches does it contain?

$$\begin{array}{lrl} \text{Length} = & 81 & \text{inches} \\ \text{Width} = & 54 & \text{,,} \\ \hline & 324 & \\ & 405 & \\ \hline & 4374 & \times \frac{3}{8} \\ & 3 & \\ \hline 8) & 13122 & \\ \hline & 1640{\cdot}25 & \end{array}$$

Ans. $1640\frac{1}{4}$ cubic inches.

To calculate the indicated horse-power from an indicator diagram, Fig. 33.

$$\frac{d^2 \times {\cdot}7854 \times 22{\cdot}55 \text{ lbs.} \times 7{\cdot}5 \times 45}{33000}$$

High-pressure cylinder

$$\begin{array}{rl} 44{\cdot}25 & \text{diameter of cylinder in inches} \\ 44{\cdot}25 & \\ \hline 22125 & \\ 8850 & \\ 17700 & \\ 17700 & \\ \hline 1958{\cdot}0625 & \text{square inches} \\ {\cdot}7854 & \\ \hline 78322500 & \\ 97903125 & \\ 156644940 & \\ 137064375 & \\ \hline 1537{\cdot}86222750 & \text{area of piston} \end{array}$$

1537·86222750 area of piston
22·55 mean-pressure obtained from indicator-card

768931113750
768931113750
307572445500
307572445500

34678·7932301250 total pressure
7·5 twice the stroke, 3 ft. 9 in. × 2 = 7 ft. 6 in.; or by decimals, 7·5 ft.

1733939661506250
2427515526108750

260090·94922593750 work done in one stroke in foot pounds
45 revolutions per minute

1300454746129687 50 } work done per minute
1040363796903750 00 } lbs. lifted per minute

33,000)11704092·71516718750(354·669
99000

180409
165000

154092
132000

220927
198000

229271
198000

312715
297000

15715

Ans. Indicated horse-power, 354¾.

[t will be observed we first multiply the diameter by
diameter (44·25 × 44·25) using decimal arithmetic,
ich is the simplest possible method of working cal-
ations where there are fractional parts. The product
nultiplied by ·7854 to find the area of the piston, or

the number of square inches on which the steam can act. We then multiply by the mean-pressure of the steam, which we found from the indicator diagram to be 22·55 lbs. per square inch, which gives the total pressure exerted on the face of the piston (34678¾ lbs.). This pressure is exerted throughout the top and the bottom stroke; and therefore it is multiplied by the length of the two strokes in feet (3 ft. 9 in., or by decimals, 3·75 ft. × 2 = 7·5 ft.), which gives the work done in one revolution, or the pounds lifted one foot high in one revolution; and as these pounds are lifted one foot high *forty-five times* a minute, we multiply by 45 revolutions, and therefore obtain the total number of pounds raised one foot high in one minute. This total divided by 33,000 lbs., which is the number of pounds a horse is supposed to lift one foot high in one minute, shows how many horses it would take to do the same work in the same time. What is understood is this: steam, having a pressure of 22½ lbs. per square inch, moving a piston, whose area is 1,537 square inches, at the rate of 337 feet per minute, is exerting a force capable of resisting the joint efforts of 354 horses, or the power is equal to 354 indicator horse-power.

To obtain the indicated horse-power from a diagram, *Fig. 34.*

$$\frac{d^2 \times \cdot 7854 \times 6\cdot 45 \text{ lbs.} \times \text{twice the stroke} \times 45}{33000}$$

Low-pressure Cylinder

79	diameter of cylinder in inches
79	
711	
553	
6241	circular inches

```
             6241  circular inches
            ·7854
         --------
            24964
           31205
          49928
         43687
         --------
        4901·6814  area of piston in square inches
             6·45  mean-pressure obtained from indicator
       ----------     diagram
        245084070
       196067256
      294100884
      -----------
     31615·845030  total pressure
              7·5  twice the stroke, 3·75 × 2 = 7·5
      ------------
     158079225155
    221310915210
    -------------
    237118·8377255 work done in one stroke, foot-lbs.
                45 revolutions per minute
    --------------
    11855941886275
    9484753509020
    --------------
33000)10670347·6976475(323·343
      99000
      -----
       77034
       66000
      ------
       110347
        99000
       ------
        113476
         99000
        ------
         144769
         132000
         ------
          127697
           99000
          ------
           28697
          =======
```

Ans. Indicated horse-power, $323\frac{3}{8}$ nearly.

Another way. By using the constant logarithm from

a table, the number of figures used is much reduced, and the result is the same.

Taking the same diagrams and particulars as before. The first point is to find at what speed per minute the engine is running.

```
    3·75 feet
      45 revolutions
   ------
    1875
   1500
   ------
   16875
       2
   ------
  337·50 feet per minute
```

Then—

By constant log. × feet per minute × by mean-pressure.

High-pressure cylinder.

```
     ·046601 log.
       337·5 speed
     -------
      233005
     326207
    139803
   139803
   ---------
  15·7278375
       22·55 mean-pressure
  ----------
   786391875
  786391875
 314556750
314556750
-------------
354·662735625
```

Low-pressure cylinder.

```
     ·148535 log.
       337·5
     -------
      742675
    1039745
    445605
   445605
  ----------
  50·1305625
        6·45
  ----------
  2506528125
 2005222500
3007833750
-------------
323·342128125
```

Indicated horse-power combined—

```
High-pressure  354·662
Low-pressure   323·342
               -------
               678·004
```

Required the average effective pressure per square inch on the piston of an engine.

RULE.—(*a*) Find the area of the piston by squaring the diameter of the cylinder, and multiplying it by ·7854; multiply by twice the stroke, and by the number of revolutions per minute. (*b*) Multiply the indicator horse-power by 33,000, and divide the product by the product *a*. The quotient gives the answer.

EXAMPLE.—Diameter of cylinder, $44\frac{1}{4}$ inches; length of stroke, 45 inches; revolutions per minute, 45; indicator horse-power, $354\frac{2}{3}$.

```
354·669
  33000
-----------
 1064007000
1064007
-----------
11704077000
===========
```

```
          44·25
          44·55
      ---------
          22125
         8850
        17700
       17700
      ---------
      1958·0625
          ·7854
      ---------
       78322500
      97903125
    156644940
   137064375
 --------------
 1537·86222750
           7·5
 --------------
   768931113750
 10766503559250
 ----------------
 11533·996706250
              45
 ----------------
   57669983531250
  46135986832000
 ----------------
 519029·851851250
 ================
```

```
519029·8518)11704077000·000(22·54
            10380597036
            -----------
            13234791640
            10380597036
            -----------
             28541946040
             25951492590
             -----------
              25904536500
              20761194072
              -----------
               5143342428
               ==========
```

Ans. 22·54 lbs. per square inch of piston.

Required the number of cubic feet of steam consumed per hour by an engine. And also the steam—equivalent as water at a given pressure.

Rule.—Square the diameter of cylinder; multiply by ·7854, by the number of revolutions per minute, by 60, by double the stroke in inches, and by the cut-off, divide by 1728, and by 437, and multiply the product by 62·5.

Example.—Diameter of cylinder, 44¼ inches; length of stroke, 45 inches; revolutions per minute, 45; steam cut-off at one-third of the stroke; pressure of steam, 45 lbs. per square inch.

```
        44·25 = diameter of cylinder
        44·25
        -----
        22125
        8850
      17700
     17700
     ---------
     1958·0625 = diameter squared
         ·7854
     ---------
      78322500
      97903125
    156644940
   137064375
   -------------
   1537·86222750 = area
```

```
                         1537.86222750=area
                                    45 revolutions
                         ______________
                          768931113750
                         615150891000
                         ______________
                        69204·40023750
                                    60 minutes in hour
                         ______________
                      4152264·01425000
                                    90 stroke 45 × 2
                         ______________
           Cut off=⅓)373703761·28250000
                       ________________
1728 inches in }  12 |124567920·42750000
a cubic foot   }     |________________
                  12 | 10380660·03562500
                     |________________
                  12 |   865055·00296800
                     |________________
                     |    72087·91691400
                     ==================

*437)72088(164·96 cubic feet                     165
     437          Weight of a cubic foot of water  62·5
     ____                                       _____
     2838                                         825
     2622                                        330
     ____                                       990
      2168                                      _____
      1748                                      10·312
      ____                                      ======
       4200
       3933
       ____
        2670
        2622
        ____
        ....
        ====
```

Answers:—

Cubic feet of steam=72,088.
Water evaporated=10·312 lbs. per hour.

A tank is 8¾ feet long and 4¼ feet broad. What height must it have to contain 1,210 gallons?

RULE.—Multiply the number of gallons (1,210) the

* The relative volume of steam at this pressure, 45 lbs., compared with water from which it was raised.

tank is required to contain, by ·16,* or divide by $6\frac{1}{4}$; the result is the contents in cubic feet. Then multiply the length by the breadth (8·75 × 4·25), and the result is the area of the bottom of the tank. Then divide the contents in cubic feet by the area, and the product is the height in feet and decimals of a foot.

```
Gallons
 1210
  ·16
 ----
 7260
1210
------
193·60 cubic feet of water.

            Feet
            8·75
            4·25
           -----
            4375
           1750
          3500
         -------
         37·1875 area of tank bottom.

        Cubic Feet
37·1875)193·60000(5·206
         1859375      12
         -------     ----
          766250    2·472
          743750
         -------
         2250000
         2231250
         -------
           18750
```

Ans. 5 ft. $2\frac{1}{2}$ in. nearly.

A tank is 7 feet long and 3 feet 4 inches broad. What height must it have to contain 900 gallons?

Ans. 6 ft. 2 in.

The stroke of an engine is 30 inches; the slide-valve travel is 5 inches; the lap is $1\frac{1}{2}$ inches, and the lead $\frac{1}{16}$ inch. At what distance from the end of the stroke will the piston be when the steam is cut off?

RULE.—Multiply the lap by 2, and add the lead; divide the sum by the travel, square the quotient, and

* 1 gallon of water = ·16 cubic foot.

multiply it by the length of stroke; the product is the distance of piston from the end of stroke when the steam is cut off.

$$\text{The distance of the piston from end of stroke} = \left(\frac{1{\cdot}5\times 2+{\cdot}0625}{5}\right)^2 \times 30.$$

$$\begin{array}{rr}
\text{Lap} = & 1{\cdot}5 \\
 & 2 \\
\hline
 & 3{\cdot}0 \\
\text{Lead} = & {\cdot}0625 \\
\hline
\text{Travel}=5) & 3{\cdot}0625 \\
\hline
 & {\cdot}6125 \\
 & {\cdot}6125 \\
\hline
 & 30625 \\
 & 12250 \\
 & 6125 \\
 & 36750 \\
\hline
 & {\cdot}37515625 \\
\text{Stroke} = & 30 \\
\hline
 & 11{\cdot}25468750 \\
\hline\hline
\end{array}$$

Ans. $11\frac{1}{4}$ in.

Required the weight to be placed at end of a safety-valve lever, to give a blowing-off pressure equal to 20 lbs. per square inch; diameter of valve 5 inches, distance from centre of valve to fulcrum 6 inches, and from valve to weight 10 inches; effective weight of the lever, or its actual pressure on the valve, 80 lbs; weight of valve 12 lbs.

Rule.—Square the diameter of the valve, and multiply by ·7854, to find the area, multiply the product by the given pressure; deduct the sum of the weight of the lever and valve; multiply the remainder by the distance from the fulcrum to the valve, and divide the

product by the distance from the fulcrum to the weight. Thus—

$$5^2 \times \cdot 7854 \times 20 - 92 \times 6 \div 16 = 112\tfrac{3}{4} \text{ lbs.}$$

```
  5           ·7854
  5              25 square of valve
 ---         ------
 25           39270
 ===         15708
             -------
             19·6350
                  20 lbs. pressure required
             -------
             392·7000
              92       lbs. weight of lever and valve
             -------
             300·7
                 6 distance from fulcrum to valve
          ( 4 | 1804·2
      16 {    |-------
          ( 4 |  451·05
              |-------
             112·76 weight required
             ======
             Ans.  112¾ lbs.
```

NOTE.—This is a very simple rule and easy to work.

A packing-ring for a cylinder 48 inches diameter is required. One is found near at hand, but it is 50 inches in diameter; how much must be cut out of it to make it fit the cylinder?

Difference of diameter $\times$ 3·1416 = inches to cut out

Ring	50	3·1416
Cylinder	48	2
Difference of diameter	2	6·2832

Ans. $6\frac{9}{32}$ in. to be cut out to make it fit.

A packing-ring for a cylinder is 89 inches diameter; before being cut was $91\frac{1}{4}$ inches. How much must be cut out of it to make it fit the cylinder?

Ans. 7·0686.

Required the cubic feet of water a pump will discharge per hour; diameter of plunger 3 inches; stroke 14 inches long, making 25 strokes a minute.

RULE.—Multiply the area of plunger by the length of stroke and revolutions per minute, and divide by 1728.

```
3"            ·7854
3                 9
-            ------
9            7·0686
                 14 stroke
             ------
             282744
             70686
             ------
            989·604 capacity of pump in inches
                 25 revolutions per minute
           --------
            4948020
           1979208
           --------
          24740·100
                 60 revolutions per hour
           -----------
        12 | 148440·6000
           -----------
1728=   12 |  12370·0500
           -----------
        12 |   1030·8375
           -----------
                85·9031
```

Ans. 86 cubic feet of water.

Weight $= 86 \times 62\frac{1}{2} = 5375$ lbs.

NOTE.—A cubic foot of water weighs $62\frac{1}{2}$ lbs.

Again. Particulars as in last question; but, suppose the pump at each stroke is $\frac{3}{4}$ths full instead of being full.

```
3            ·7854
3                9
-           ------
9           7·0686 area of plunger end
```

```
         7·0686 area of plunger end
             14 length of plunger
        -------
        282744
        70686
        -------
        98·9604 total area in length of stroke
             25 stroke
        -------
       4948020
      1979208
      ---------
      2474·0100 ⎫
              3 ⎪
      --------- ⎬ 3/4 full
    4)7422·0300 ⎪
      --------- ⎪
      1855·5075 ⎭
             60 inches
        ----------------
      12 | 111330·4500
         |-------------
1728= 12 |   9277·5375
         |-------------
      12 |    773·1281
         |-------------
               64·4273
               =======
```

Ans. $64\frac{1}{2}$ cubic feet of water.

Parts of a 48-inch stroke.

40 inches	$\frac{5}{6}$	6 inches	$\frac{1}{8}$
32 „	$\frac{2}{3}$	4 „	$\frac{1}{12}$
24 „	$\frac{1}{2}$	3 „	$\frac{1}{16}$
16 „	$\frac{1}{3}$	2 „	$\frac{1}{24}$
12 „	$\frac{1}{4}$	1 „	$\frac{1}{48}$
8 „	$\frac{1}{6}$		

The steam is cut off at $\frac{1}{3}$rd of the stroke of 42 inches; what is the distance the piston has travelled?

```
3)42 inches
  --
  14 inches.  Ans.
  ==
```

Again. The steam is cut off at $\frac{1}{8}$th of the stroke.

```
8)42 inches
  --
  5¼ inches.  Ans.
  --
```

What is $\frac{5}{6}$ths of the same stroke of piston?

$$\begin{array}{r} 42 \\ 5 \\ \hline 6)210 \\ \hline 35 \text{ inches.} \end{array}$$

If the piston, having a 42-inch stroke, comes to rest at $\frac{1}{12}$th of the stroke, what distance is it from the nearest cover, neglecting the clearance, and the obliquity of the connecting-rod?

$$\begin{array}{r} 12)42 \\ \hline 3\tfrac{1}{2} \text{ inches.} \end{array}$$

Prove it—

$$\begin{array}{r} 3\tfrac{1}{2} \\ 12 \\ \hline 42 \end{array}$$

Prove that 35 inches is $\frac{5}{6}$ths of 42 inches.

$$\begin{array}{r} 35 \text{ inches} \\ 6 \\ \hline 5)210 \\ \hline 42 \text{ inches.} \quad \text{Ans.} \end{array}$$

APPENDIX.

TO TEST THE QUALITY OF IRON.

If the fracture gives long silky fibres, of leaden-grey hue, fibres cohering and twisting together before breaking, the iron may be considered a tough, soft iron.

A medium even grain, mixed with fibres—a good sign.

A short blackish fibre indicates badly refined iron.

A very fine grain denotes a hard steely iron, apt to be cold-short, hard to work with a file. Coarse grain, with brilliant crystallized fracture, yellow or brown spots, denotes a brittle iron, cold-short, working easily; when heated welds easily.

Cracks on the edges of bars, sign of hot-short iron.

Good iron is readily heated, soft under the hammer, throws out but few sparks.

Iron, with heating, if exposed to air, will oxidize; when at white heat, if in contact with coal, will carbonize, or become steely.

To restore burnt iron—give a smart heat, protected from the air, if injured by cold hammering; anneal slowly and moderately, if hard or steely; give one or more smart heats to extract the carbon.

KNOTS.

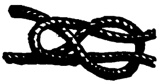


Fig. 35.—A Common Bend.

A Common Bend.—It is formed by passing the end of a rope through the bight of another rope, then round both parts of a rope and down through its own bight.

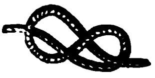


Fig. 36.—Figure of Eight Knot.

Figure of Eight Knot.—Take the end of the rope round the standing part, under its own part and through the lower bight.

Fig. 37.—Timber Hitch.

Timber Hitch.—It is made by taking the end of a rope round a spar, passing it under and over the standing part, and then passing several turns round its own part.

Fig. 38.—A Fisherman's Bend.

Fisherman's Bend.—With the end of a rope take two turns round, then form a half-hitch round the standing part, and under the turns, and another half-hitch round the standing part.

Fig. 39.—Two Half-hitches.

To make Two Half-hitches.—Pass the end of the rope round the standing part, and bring it up through the bight—this is one half-hitch; two of these, one above the other, constitute two half-hitches.

Fig. 40.—Overhand Knot.

Overhand Knot.—This is made by passing the end of the rope over the standing part and through the bight.

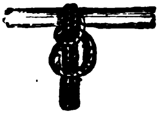


Fig. 41.—Rolling Bend.

Rolling Bend.—It is something similar to a fisherman's bend. It is two round turns round a spar, two half-hitches around the standing part, and the ends stopped back.

To make a Bowline Knot.—Take the end of the rope in your right hand, and the standing part in your left; lay the end over the standing part, then with your left hand turn the bight of the standing part over the end part; then lead the end through the standing part above, and stick it down through the cuckold's neck formed on the standing part, and it will appear as the sketch.

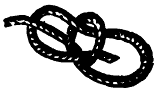


Fig. 42.—A Bowline Knot.

A Reef Knot.—First make an overhanded knot, supposing it to be round a yard; then bring the end being to you over the left hand, and through the bight haul both ends taught. This knot is used chiefly for joining the ends of ropes or lines together.

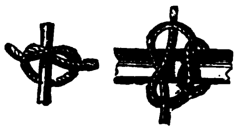


Fig. 43.—Square or Reef Knot.

A Short Splice.—A short splice is made by unlaying the ends of two ropes, or the two ends of one rope, to a sufficient length, then crutch them together as per adjoining sketch; draw them close and push the strands of one under the strands of the other, the same as the eye-splice. This splice is used for block-straps, slings, &c. If the ends are to be served over, they are but once stuck through; if not, they are stuck twice and cross-whipped across the strands, so as to make them more secure. When the ends are to be served, take a few of the underneath yarns, enough to fill up the lay of the rope for worming, then scrape or trim the outside ends, and marl them down ready for serving.

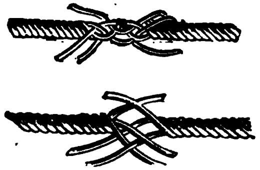


Fig. 44.—Short Splice.

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THE END.

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